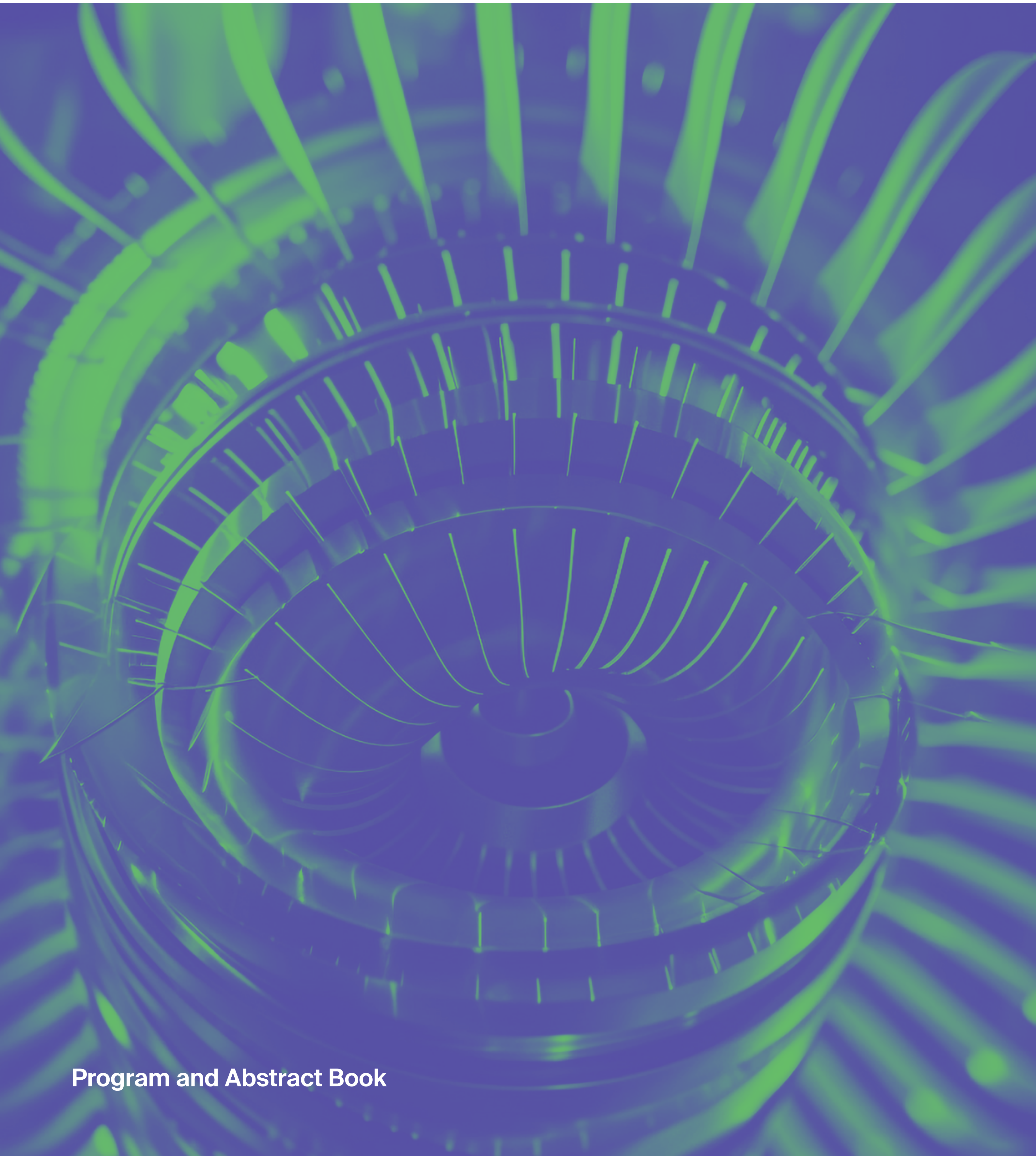
IECAT 2024 Conference

The 2nd International Electronic Conference on Actuator Technology

04–06 November 2024 | Online



Program and Abstract Book

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The 2nd International Electronic Conference on Actuator Technology

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Welcome from the Chairs

Dear Colleagues,

You are cordially invited to participate in the 2nd International Electronic Conference on Actuator Technology (IECAT), sponsored by MDPI's open access journal Actuators. The meeting is an opportunity for researchers in the field of actuator engineering and technology to present their research and exchange ideas with colleagues. This is a virtual conference via Zoom.

This Second Conference will focus on "Sustainability and Crisis Technologies", in addition to general topics in accordance with the aims and scope of the journal Actuators.

-New actuator materials - Piezoelectrics, Magnetostrictors, Shape memory alloys; Elastomer actuators
-Innovative actuator designs - Ultrasonic motor; MEMS/NEMS
-New actuators for control systems, Intelligent control, Fault and attack-tolerant control, Power supply, Switching regulator, AC/DC converter
-Remarkable actuator applications - Biomedical actuators, Robotics, Crisis technologies, Aerials, Surface and underwater vehicles; Energy harvesting

Your submitted paper will be reviewed and published in a Special Issue of the journal Actuators with a discount of 20% on the article processing charge (ISSN 2076-0825; Actuators).

We look forward to engaging in exciting discussions and hearing new ideas and perspectives from experts in the actuator field. All participants are welcome to join the online conference.

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Professor Víctor Ruiz-Díez

The University of Castilla–La Mancha, Ciudad Real, Spain

Program at a Glance

	Day 1	Day 2	Day 3
Afternoon	**Session 1.** New actuator materials	**Session 2.** Innovative actuator designs	**Session 3.** Drive/control technologies **Session 4.** Remarkable actuator applications

IECAT 2024 Program

4th November 2024 (Monday)

Session 1. New actuator materials

Time: 13:00 (CET, Basel) | 7:00 (EDT, New York) | 21:00 (JST, Tokyo)

Time in CET	Speakers	Title
13:00–13:10	**Prof. Dr. Kenji Uchino** Event chair	*Welcome from the Event Chair*
13:10–13:50	**Prof. Dr. Kenji Uchino** Event chair	Piezoelectric Actuator – History “From Discovery to Commercialization”
13:50–14:20	**Dr. Aslan Miriyev** Session chair	Soft Actuation in the Era of Physical AI
14:20–14:50	**Dr. Weimin Huang** Keynote Speaker	Laminated Composites with High Tan Delta over Wide Temperature Range
14:50–15:20	**Dr. Brittany Newell** Invited Speaker	Additively Manufactured Actuators
15:20–15:35	**Ouriel Bliah** Invited Speaker	Digital light processing 3D printing of stretchable and compressible porous polymers for soft robotics

5th November 2024 (Tuesday)

Session 2. Innovative actuator designs

Time: 13:00 (CET, Basel) | 7:00 (EDT, New York) | 21:00 (JST, Tokyo)

Time in CET	Speakers	Title
13:00–13:10	**Prof. Dr. José Luis Sánchez-Rojas** Session chair	*Welcome from the Session Chair*
13:10–13:40	**Prof. Victor Ruiz** Invited speaker	Hybrid 3D-printed and MEMS Sensors and Actuators
13:40–14:10	**Dr. Manmatha Mahato** Invited Speaker	Structural Carbon Materials for Electrochemical Soft Actuators
14:10–14:25	**Víctor Gómez Corsino** Invited Speaker	Advanced AI-Integrated Sensor Systems for Liquid Monitoring: From 3D-Printed Resonators to Piezoelectric MEMS actuators
14:25–14:40	**Daniel Calegaro** Invited Speaker	A piezo-actuated on-chip testing device for the micromechanical characterization of the SiO_2-polysilicon interface
14:40–14:55	**Heming Liu** Invited Speaker	Binder Jet Print Based Electromechanical Actuator Design

6th November 2024 (Wednesday)

Session 3. Drive/control technologies

Time: 14:00 (CET, Basel) | 8:00 (EDT, New York) | 22:00 (JST, Tokyo)

Time in CET	Speakers	Title
14:00–14:10	**Prof. Dr. Paolo Mercorelli** Session chair	*Welcome from the Session Chair*
14:10–14:40	**Prof. Dr. Satoshi Ueno** Invited speaker	Principle and analysis of a five-axis active suspended axial-gap self-bearing PM motor
14:40–15:10	**Prof. Dr. Dong Jiang** Keynote Speaker	The role of forest diversity and vegetation dynamics in face of extreme meteorological and biological events in the South Eastern Alps
15:10–15:40	**Prof. Dr. Paolo Mercorelli** Keynote Speaker	Some Control Strategies for MagLev Actuators
15:40–15:55	**Uros Ilic** Invited Speaker	The electromagnetic vibratory actuator load during the transport of a rigid body on a vibratory conveyor
15:55–16:10	**Cristian Napole** Invited Speaker	Advanced control strategies based on reinforcement learning for linear actuators
16:10–16:25	**Han Wang** Invited Speaker	Colibri: Hovering Flight of a Robotic Hummingbird

Session 4. Remarkable actuator applications

Time: 16:25 (CET, Basel) | 10:25 (EDT, New York) | 00:25 (JPT, Tokyo)

Time in CET	Speakers	Title
16:25–16:55	**Prof. Dr. Norman M. Wereley** Session chair	Additive Manufacturing in Magnetorheological Systems: MR Elastomers, Encapsulants and Cellular Materials
16:55–17:10	**Ved Prakash Dubey** Invited Speaker	Controlled Deployment of Polymeric Composite Hinges for Space Applications
17:10–17:25	**Carl Johan Gøbel Nielsen** Invited Speaker	Adaptive Deployable Polymer Reflector for CubeSats
17:25–17:40	**Maxim Wischnewski** Invited Speaker	A Multilayer Piezoelectric Thermo-Magnetic Film Generator
17:40–17:55	**Abhiram Gunaratnam** Invited Speaker	An electric linear actuator-based lysimeter soil retriever design: Performance optimization and performance loss measurement
17:55–18:10	**Ziyue Piao** Invited Speaker	Assessing the Impact of Force Feedback in Musical Knobs on Performance and User Experience

Session 1. New Actuator Materials

sciforum-099989: Digital light processing 3D printing of stretchable and compressible porous polymers for soft robotics

Ouriel Bliah [1,*], Seonggun Joe [2], Roei Reinberg [1], Lucia Beccai [2] and Shlomo Magdassi [1]

[1] Casali Center for Applied Chemistry, Institute of Chemistry, Hebrew University of Jerusalem, Jerusalem, Israel
[2] Soft Biorobotics Perception Lab, Istituto Italiano di Tecnologia, Genova, Italy

This study introduces an approach for developing highly stretchable and compressible porous materials for soft robotics applications using vat photopolymerization 3D-printing technology. The materials are developed by a stable photopolymerizable water-in-oil (W/O) emulsion, where water droplets function as pore templates, and a polyurethane diacrylate forms the surrounding stretchable matrix. The emulsion is created by mixing the dispersed aqueous phase with the continuous phase containing photoinitiators and emulsifiers, resulting in a stable emulsion suitable for 3D printing. Finally, after photopolymerization and subsequent removal of the internal water droplets, an open-cell structure is achieved, exhibiting a remarkable elongation-at-break of 450% and excellent reversible compressibility at 80%. These properties endow the material with both high compliance and strength, essential for actuator performance. Furthermore, this method allows the fabrication of high-resolution complex objects with customized porosity, incorporating both macro-pores by design and inherent micro-pores. The potential of these materials is demonstrated through the creation of novel actuators for soft robotics, showcasing unique actuation performance, shape adaptability, and high holding force. The high compliance of this material is particularly relevant for actuators as it enables efficient deformation under low energy inputs, enhancing the performance and energy efficiency of soft robotic systems.

sciforum-104632: Fundamental Characteristics of Stiffness-Adjustable Soft Actuator Made of Three Functional Polymer Materials Using FDM 3D Printer

Kai Sawada *, Shuichi Wakimoto, Daisuke Yamaguchi and Takefumi Kanda

Master's Course Intelligent Mechanical Systems Course, Degree Program in Mechanical Systems and Urban Innovation Science, Division of Environmental, Life, Natural Science and Technology, Graduate School of Environment, Life, Natural Science and Technology

Background and purpose

Soft actuators are characterized by high safety and shape adaptability due to their high softness. However, their low rigidity makes them unsuitable for tasks requiring high load capacity, such as grasping and manipulating heavy objects. Therefore, actuators with stiffness-adjustable materials are being developed [1][2]. They can change their own stiffness and improve their load capacity while maintaining the shape adaptability that is a strong point of soft actuators. The purpose of this study is to fabricate a stiffness-adjustable soft actuator using a normal FDM 3D printer.

Structure

The actuator to be developed consists of a conductive material, a flexible material, and SMP (Shape Memory Polymer). The actuator function is achieved by a flexible material with a bellows structure on one side, which is curved by air pressure. The conductive material is used to heat the SMP which becomes less rigid upon heating. The stiffness of the actuator is variable, allowing the actuator to be driven in a low-stiffness state and then made stiff to maintain the curvature.

Experiments

The actuator consists of a conductive material in the shape of a U, SMP in the shape of a plate, and a flexible material in the shape of a bellows actuator. By applying electric power of 90 W to the conductive material, the thermal characteristics were investigated by using thermal sensor experimentally. Figure 1 illustrates the temperature profile of the actuator, while Figure 2 depicts the actuator's appearance in its curved posture. After 60 seconds, it became 65.1 °C from 18.6 °C which is the room temperature. It is enough high to be rubbery state of the SMP, and under this condition, pneumatic pressure was applied up to 400 kPa, resulting in a curvature of 18.3 m^{-1} at maximum. Additionally, the driving characteristics were investigated in a high stiffness state without applying power. The result was 1.32 m^{-1} at 400 kPa, confirming that different curving quantity can be achieved at different stiffness levels. Furthermore, the stiffness was varied after curving, and the tip force was measured. When the load cell was pushed down the actuator's tip to be the curvature of 10.6 m^{-1} from the maximum curvature while maintaining the rubbery state by application of electric power, the reaction force was 125.2mN. Conversely, when the actuator became rigid state by stopping the application of electric power and cooling naturally to the room temperature, the tip force was 140.5mN.

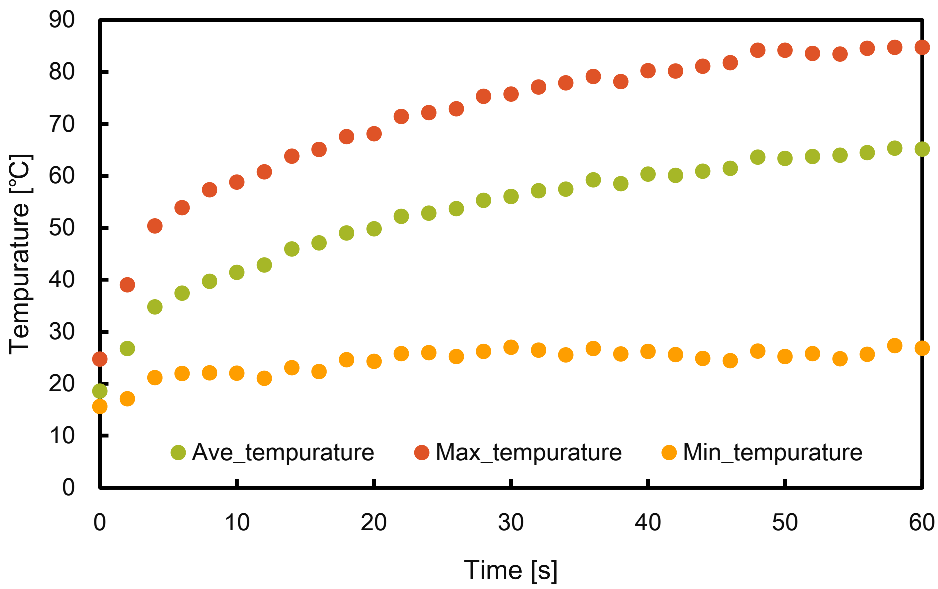

Figure 1. Temperature changes during actuator heating.

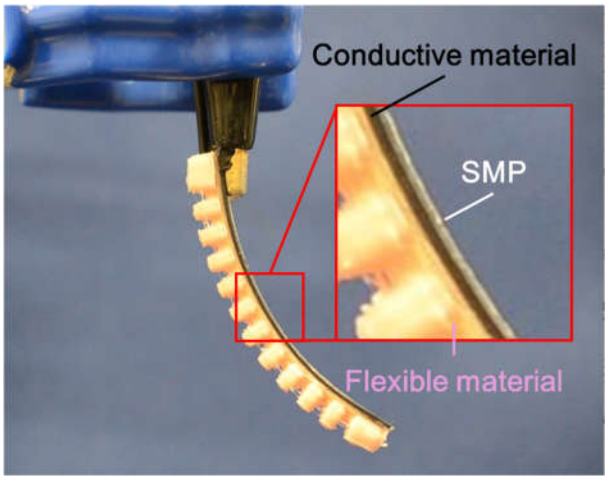

Figure 2. Overview of the actuator and its posture when curved

The developed actuator can be curved at low stiffness condition and its stiffness can be higher with maintaining the deformation state. Therefore, the actuator is expected to be applied to robot hands capable of grasping heavy objects.

Acknowledgments

This study was partly supported by JSPS KAKENHI Grant Number JP23K03644 and JKA through its promotion funds from KEIRIN RACE

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2. Zhang, Y.; Zhang, N.; Hingorani, H.; Ding, N.; Wang, D.; Yuan, C.; Zhang, B.; Gu, G.; Ge, Q.; Fast-Response, Stiffness-Tunable Soft Actuator by Hybrid Multimaterial 3D Printing. Advanced Functional Materials, 2019, Vol.29,1806698.

Session 2. Innovative Actuator Designs

sciforum-099984: A double-sided fixed common mass block vector hydrophone based on the relaxation ferroelectric single crystal shear vibration mode

Ruixuan Liu *, Fei Li and Xiangyu Gao

Key Laboratory of Electronic Ceramics and Devices of the Ministry of Education， Xi'an Jiaotong University, Xi'an City, Shaanxi Province, China

Vector hydrophones play an important role in underwater acoustic detection systems. In response to the low bandwidth problem of traditional piezoelectric ceramic based single-sided fixed cantilever beam structure hydrophones and the difficulty in miniaturization of compression type hydrophones, this paper proposes a double-sided fixed common mass block vector hydrophone based on the relaxation ferroelectric single crystal shear vibration mode. The vector hydrophone proposed in this article achieves higher receiving sensitivity due to the use of high-performance relaxor ferroelectric single crystals. The design structure using shear vibration mode is more conducive to miniaturization, and the double-sided fixed common mass block design is used to obtain higher working receiving frequency bandwidth. Simulation results show that the first-order resonant frequency of the double-sided fixed common mass block type vector hydrophone proposed in this article is 47 kHz, which is more than twice the first-order resonant frequency of the single-sided fixed vector hydrophone. The vector hydrophone proposed in this article is beneficial for the integration of underwater acoustic detection systems and the broadening of information sources.

sciforum-103172: A piezo-actuated on-chip testing device for the micromechanical characterization of the SiO2-polysilicon interface

Daniel Calegaro [1,*], Stefano Mariani [1], Massimiliano Merli [2] and Giacomo Ferrari [2]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, 20133, Italy
[2] STMicroelectronics, Cornaredo, 20007, Italy

Microelectromechanical systems (MEMS) have recently allowed to attain unprecedented results in different fields of applications, due to their versatile functionalities. In light of the continuous trend towards miniaturization, MEMS reliability is becoming more and more a critical concern, especially in dynamic environments characterized by shocks and repeated loadings. The interplay between the said external excitations and possible microfabrication defects, can detrimentally affect the long-term performance of inertial MEMS. In this research activity, focusing on the Silicon-on-Insulator (SOI) technology the reliability issues are studied as mainly driven by mechanical actions, in cases leading to a fatigue-induced delamination of polysilicon films from the substrate. By exploiting a piezoelectric actuation to induce vibrations characterized by kHz frequencies, the geometry of the movable parts of a testing device is optimized to maximize the stress leading to delamination. Results are presented for a statically-indeterminate structure, designed in order to cause a delamination of epitaxial polysilicon from silicon dioxide under cyclic loadings.

sciforum-100046: A Relaxor Ferroelectric Crystal Based Two-DOF Miniature Piezoelectric Motor with Fish Body Structure

Haonan Jin *, Xiangyu Gao, Kaile Ren and Fei Li

Xi 'an Jiaotong University

Multi-dimensional movements and miniaturization are required for robotic joints motion, multi-axis optical alignments and other multiple degree-of-freedom (DOF) actuation scenes. However, it is a challenge for piezoelectric motors to guarantee multi-DOF movements, miniaturization, high load capacity and high resolution simultaneously. Inspired by synergic movement of body and caudal fin of fish in nature and the construction idea of metamaterials, we proposed a two-DOF linear piezoelectric motor (4mm^{Height}×3mm^{Length}×3mm^{Width}) based on the artificial elongation 31_z and shear $35_{x/y}$ mode by using $Pb(In_{1/2}Nb_{1/2})O_3$–$Pb(Mg_{1/3}Nb_{2/3})O_3$–$PbTiO_3$ (PIMNT) relaxor ferroelectric single crystal as piezoelectric elements. The results demonstrate that the motor is capable of achieving bidirectional motion in both X and Y axes, with the PIMNT crystal-based motor reaching a velocity of up to 94.8 mm/s. Its mechanical loading capacity per unit volume reaches as high as 1.39 mN/mm^3, which exceeds the load capacity of currently reported two-DOF motors by 10 times. Moreover, it exhibits an exceptional step resolution of 5 nm, outperforming existing two-DOF motors by 1-2 orders of magnitude in terms of precision and accuracy. Furthermore, by modulating the driving signals of this motor, it can traverse any trajectory within the XY plane. The proposed ultrasonic motor has potential for applications in micro-robots, nano-precision motion, automatic visual systems and haptic interfaces.

sciforum-099971: Binder Jet Print Based Electromechanical Actuator Design

Heming Liu * and Haiyan Henry Zhang

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Additive manufacturing has garnered significant attention due to its ability to replace conventional casting methods, resulting in cost reduction while meeting the increased demands for performance and cost-effectiveness in hydraulic valve bodies within the industry. Binder jet print (BJP), an additive manufacturing technique applicable to metal materials, presents new opportunities for innovating valve system production methods. This approach also allows for the redesign of electro-hydraulic systems traditionally limited by casting processes. Conventional methods often struggle to fabricate multifunctional parts without compromising functional performance or requiring additional supporting structures for manufacturability. However, the advancement of additive manufacturing technologies enables integrated actuator design and manufacturing, liberating them from these conventional constraints. These technologies facilitate the achievement of enhanced performance and multifunctional requirements for actuators, merging design and manufacturing into a cohesive domain where material and structure considerations are integrated.

In this research, we propose a compact valve system supporting body structure, considering material properties, functionality, limitations of binder jet print, dimensions, and manufacturing shrinkage. Binder jet print offers the possibility of replacing two die-casting parts with a single additive manufacturing part, necessitating the rearrangement of the possible spacer plate. Additionally, spool valves and pilot solenoids are redesigned to fit the new valve body housing. To streamline the assembly process and mitigate the drawbacks of BJP technology, spool valve sleeves are innovatively introduced into the transmission valve body design. The newly designed spool valves, assembled in the BJP valve body, aim to deliver equal or superior static response performance. This research also discusses special designs for additional components such as pressurized vents, check ball valves, and mounting parts.

This study represents a pioneering attempt to apply binder jet print to the complex industrial valve body system, with the goal of redesigning a lighter, smaller, and more cost-effective valve body. The valve actuator supporting shell is redesigned for one-step molding, and the hydraulic path is reconfigured while preserving functionality. Material considerations for the valve actuator supporting shell are addressed to mitigate deformation caused by post-processing, which may lead to the leakage issues arising from the porosity of the valve body shell. By integrating all orifices into spool valve sleeves, we achieve the same or improved pressure drop control.

Moreover, the application of binder jet print in valve body manufacturing provides an opportunity to explore new material compositions and structural designs that were previously infeasible with traditional casting methods. This flexibility allows for the incorporation of advanced features such as optimized fluid flow channels, enhanced thermal management, and reduced weight, all of which contribute to the overall efficiency and performance of the hydraulic system. The integration of these features is critical for meeting the demanding operational requirements of modern industrial applications, where reliability and precision are paramount.

To validate the feasibility and advantages of the binder jet print valve body, this research includes a comprehensive comparative analysis of the static response performance. Additionally, we explore the potential for further enhancements in valve body design through iterative testing and optimization, paving the way for future advancements in the field of hydraulic valve systems.

In conclusion, this research demonstrates the significant potential of binder jet print as an innovative manufacturing method for hydraulic valve bodies. By addressing the limitations of conventional casting and offering new design possibilities, binder jet print stands to revolutionize the production of hydraulic components, leading to more efficient, cost-effective, and high-performance systems. This work lays the foundation for future studies and applications of additive manufacturing in the industrial sector, highlighting the transformative impact of this technology on traditional manufacturing processes.

sciforum-098261: Realizing a novel variable stiffness actuator with a multi-pulley-spring system

Vu Linh Nguyen

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This paper presents the design of a variable stiffness actuator (VSA) using a multi-pulley system with a linear spring. To generate compliance for the VSA, twelve outer and six inner pulleys are evenly arranged around a center and are serially connected to a spring through a cable. The spring gets extended when the inner pulleys rotate about the center. The output stiffness is determined as the derivative of the elastic force exerted on the cable with respect to the time, and it can be varied by adjusting the locations of the inner pulleys. This design employs a cam disk to move the pulleys simultaneously, resulting in a compact design. This paper provides the design concept, theoretical analysis, and numerical examples to demonstrate the proposed VSA and its performance. Through some examples, it is found that the VSA can provide a maximum torque of 30 N-cm with a maximum defection of 40 degrees. These results can present a wide application and high adaptability of the proposed design to various robotic systems and devices.

sciforum-108431: Modeling and Performance Optimization of a Lithium Niobate-Based Pyroelectric Sensor Using Finite Element Analysis

Kiran Keshyagol [1,*] and Santosh Madiwal [2]

[1] Department of Mechatronics, Manipal Institute of Technology, Manipal Academy of Higher Education
[2] Department of Electrical Engineering, KIT's College of Engineering (Autonomous), Kolhapur 416234, India

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This study presents a detailed analysis of a pyroelectric detector based on a lithium niobate ($LiNbO_3$) crystal for optimizing its performance under different geometrical configurations and electrical load conditions. The effect of varying the pyroelectric disk radius and thickness, as well as the electrical load resistance, on voltage, current, power, and temperature profiles, was thoroughly investigated. Results indicate that larger disk radii (up to 5 mm) enhance voltage and current sensitivity, thereby maximizing power output. However, larger radii also lead to slower temperature decay, highlighting the need for efficient thermal management to prevent structural overheating and maintain long-term functionality. Additionally, increasing the disk thickness from 0.01 mm to 0.04 mm results in substantial improvements in voltage, current, and power, with the most significant changes occurring between 0.01 mm and 0.02 mm. Conversely, thicker disks show better heat dissipation, helping mitigate temperature rise. The analysis of varied electrical load resistances reveals that lower resistances (1 kΩ) generate higher power and voltage outputs, while higher resistances reduce the system's electrical response. These findings underscore the importance of optimizing both geometrical and electrical parameters to enhance the overall performance and thermal stability of pyroelectric detectors in practical applications. These findings provide valuable insights for optimizing pyroelectric sensor performance through geometric and electrical load adjustments. Future work includes the fabrication of the sensor using the optimized parameters, followed by experimental validation to assess its real-world performance.

sciforum-108279: Advanced AI-Integrated Sensor Systems for Liquid Monitoring: From 3D-Printed Resonators to Piezoelectric MEMS actuators

Víctor Gómez Corsino *, Víctor Ruiz-Díez and José Luis Sánchez-Rojas

Universidad de Castilla-La Mancha

Keywords: 3D-printed; MEMS; microcontroller; machine learning; olive oil

In modern industry, the integration of sensors with advanced artificial intelligence (AI) algorithms is essential for enhancing workflow efficiency and decision-making capabilities. This work introduces two innovative approaches that use these technologies to monitor and analyze liquid properties in real-time, shown in Figure 1. In the first approach (Figure 1 (a)), we designed a cuboid-shaped fluidic cell [1], fabricated from various materials using novel 3D printing techniques, featuring a vibrating membrane at its base with two external piezoelectric actuators attached. The second approach (Figure 1 (b)) employed micromachined plates driven by AlN piezoelectric films, fabricated using MEMS technology, meticulously designed to achieve quasi-free-free vibration in the (0,5) mode [2]. Both types of sensors used a two-port structure, one for actuation and the other for detection. The integration of these devices with AI techniques allowed us to use frequency responses in a range with multiple resonances, highly sensitive to fluid properties [3], while eliminating the need for complex electronics to process and acquire data.

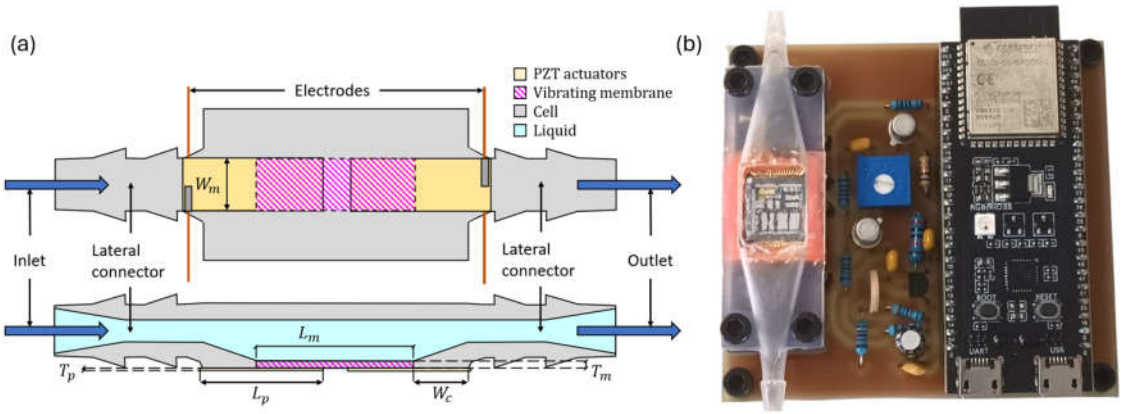

Figure 1. (**a**) Top and cross-sectional views of the 3D-printed liquid cell with piezoelectric actuators. (**b**) Portable, low-cost viscometer-densimeter that included a MEMS microresonator, a microcontroller unit, and conditioning electronic circuits. The system incorporated a 3D-printed fluidic cell for injecting liquid into the sensor.

The spectra obtained with the sensors were subjected to various advanced data processing and machine learning techniques, performing an exhaustive search for the optimal combinations of hyperparameters that best fit the sensor data. Convolutional neural networks (CNNs) were found to be highly effective in working with frequency characteristics and estimating the viscosity and density of different types of liquids. In the second approach, these models were implemented on a microcontroller board, which also managed all electronics and communication with the sensor, resulting in a precise, compact, portable, and low-cost device.

Cell-based systems proved effective for monitoring the properties of aqueous solutions, achieving calibration errors below 2% and resolutions of $7.79 \cdot 10^{-3}$ mPa·s for viscosity, and $1.09 \cdot 10^{-3}$ g/mL for density. The microelectromechanical resonator-based instrument was capable to detect very small adulterations in olive oil with other vegetable oils, as low as 2%, with calibration and resolution errors of 0.47% and 0.14 mPa·s for viscosity, and 0.0331% and $9.25 \cdot 10^{-5}$ g/mL for density. The calibration and resolution accuracies obtained were comparable to or exceeded those in the state of the art, and were on par with other commercial laboratory instruments of greater complexity, cost, and stationary nature.

Our findings demonstrate the significant potential of integrating sensors with machine learning techniques to achieve accurate detection of physical properties in fluids and address complex and critical industrial challenges, such as olive oil fraud. These advancements pave the way for the development of next-generation sensors that are not only accurate and reliable but also scalable and adaptable to diverse applications, providing valuable tools for the new industry.

Author Contributions: Víctor Corsino: Methodology, Investigation, Data curation, Validation, Visualization, Software, Resources, Writing, Review, Editing. Víctor Ruiz-Díez: Investigation, Resources, Writing, Review, Editing. Jose Luis Sánchez-Rojas: Conceptualization, Methodology, Investigation, Supervision, Project administration, Resources, Writing, Review, Editing.

Acknowledgments and Funding: Universidad de Castilla-La Mancha, through Grant PID2023-146163OB-I00 by MCIN/AEI and FEDER 'ERDF A way of making Europe'.

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Session 3. Drive/Control Technologies

sciforum-104897: The electromagnetic vibratory actuator load during the transport of a rigid body on a vibratory conveyor

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During a vibrational transport of a rigid body on a vibratory conveyor having electromagnetic vibratory actuator, a rigid body exerts by equal, but opposite force to a surface's reaction force. This paper covers research on a reactive force that the body exerts on the EVA during its relative motion. The reactive force is a vector sum of the surface's normal contact force and tangential force of friction, modeled with the Coulomb friction model. For a general case of vibratory transport, the friction force is defined and given as a piecewise function. Additionally, differential equations for the rigid body's relative motion are defined and solved to find potential moments in time when the body starts and stops with relative motion. During the period of the relative motion, a dynamic friction force is used. Conditions for a special case of a no-hopping motion are defined and presented graphically. For a given vibratory conveyor and vibratory regime a graph for reactive force that acts as a load on the EVA is shown. Computer simulation using Solidworks® is performed and its results are compared to the previously obtained mechanical model.

sciforum-099629: Active Disturbance Rejection Control of an Electro-Hydrostatic Actuator

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Active Disturbance Rejection Control (ADRC) is widely applied in automatic machines, like electric motors, proved effective in performance enhancement. However, there is little report in its application in Electro-Hydrostatic Actuators (EHAs), where hydrostatics and power electronics coupled heavily. This paper gives both theoretical and experimental study on ADRC application in an EHA for the thrust vector control of a launcher. The mathematical model and state space model of the system were established and the system disturbances were estimated and compensated. The performances were compared to the counterpart using traditional proportional-integral-differential (PID) algorithm. It shows that ADRC is more effective than PID in rejecting system disturbances and model uncertainties，significantly reducing tracking errors and improving EHA dynamics.

sciforum-101864: Advanced control strategies based on reinforcement learning for linear actuators

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This work explores the application of reinforcement learning (RL) for advanced control of linear actuators in a simulated environment. We present the development of an RL agent using Python libraries to control the position of a linear actuator modelled with a specific dynamic system. The agent interacts with the simulated environment, receiving rewards based on its performance in achieving desired positions. Through continuous learning and exploration, the agent refines its control strategy, surpassing traditional methods in terms of improved accuracy and tuning effort. This approach offers a data-driven solution for complex control problems, particularly beneficial for actuators with non-linearities or uncertainties.

sciforum-099139: Colibri: Hovering Flight of a Robotic Hummingbird

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This paper explores the design, development and testing of a tailless, two-winged robotic hummingbird, named COLIBRI. The current version of our robot has a total mass of around 22 gr, a wingspan of 21cm and a flapping frequency of around 20Hz. The primary objective is to enhance its flight autonomy and stability. The control system incorporates two attitude reconstruction algorithms: a Complementary filter and a full state dynamic observer implemented as a Kalman filter. Both of them were designed to filter out the noise caused by the rapid flapping of the wings, ensuring accurate and reliable attitude estimation. They are implemented on a newly developed control board with enhanced performance and reduced weight. Experimental results demonstrate successful attitude stabilization and improve station keeping, despite significant flapping noise. Notably, the gear-based prototype achieved a maximum flight time of 4 minutes and 45 seconds, highlighting the effectiveness of the design improvements in extending flight duration.

sciforum-106211: Optimizing solar efficiency: MPPT control using PSO metaheuristics under partial shading constraint

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In photovoltaic (PV) systems, efficient energy extraction is critical, especially under partial shading conditions where multiple local maxima can complicate the search for the true Maximum Power Point (MPP). This paper presents a robust approach to Maximum Power Point Tracking (MPPT) using the Particle Swarm Optimization (PSO) metaheuristic, tailored specifically for partial shading scenarios. The PSO method is advantageous due to its ability to handle the complex, non-linear nature of the power-voltage (P-V) and current-voltage (I-V) characteristics under varying irradiance levels. Unlike conventional MPPT techniques, which may converge to local maxima, the PSO-based method dynamically adjusts the duty cycle of the DC-DC converter, efficiently navigating the search space to locate the global MPP. The proposed method is evaluated through extensive simulations, where it consistently demonstrates superior performance in tracking the true MPP, regardless of the shading pattern. The paper provides a detailed analysis of the P-V and I-V curves under different shading conditions, showcasing how the PSO algorithm outperforms traditional methods in both convergence speed and accuracy. The results indicate a significant improvement in the power output of the PV system, highlighting the effectiveness of PSO in optimizing energy harvest. This study contributes to the growing field of renewable energy by offering a reliable and efficient solution for maximizing power generation in partially shaded PV systems.

sciforum-108637: Drone trajectory tracking control: A comparative study of PID, Sliding mode, and Backstepping controllers enhanced by Gray Wolf Optimization

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Unmanned Aerial Vehicles (UAVs) are transforming various fields, from surveillance to agriculture, necessitating advanced control systems for effective operation. This study explores three prominent control strategies for UAV trajectory tracking: Proportional-Integral-Derivative (PID) control, Sliding Mode Control (SMC), and Backstepping Control. Each method is enhanced through Gray Wolf Optimization (GWO), a nature-inspired algorithm designed to determine the optimal control gains, thereby maximizing performance in real-world scenarios. The paper begins by providing a thorough overview of each control technique, elucidating their underlying principles and typical applications in UAV systems. We employ GWO to fine-tune the parameters of each controller, enabling a systematic approach to optimization that takes advantage of the algorithm's ability to converge towards global optima. This optimization is critical, as the success of UAV operations heavily relies on precise trajectory tracking, which is inherently influenced by the selected control strategy. To evaluate the effectiveness of each approach, we conduct a series of simulations that track the UAV's performance across various trajectories. Key performance indicators such as speed, precision, and robustness are meticulously analyzed. The results illustrate significant variances in how each controller performs under different operational conditions, with a detailed discussion of their respective advantages and limitations. For instance, while the PID controller is noted for its simplicity and ease of implementation, it may struggle with robustness in dynamic environments. In contrast, the Sliding Mode Controller exhibits superior resilience to disturbances, yet may require more complex tuning. The Backstepping Control method, on the other hand, demonstrates exceptional precision, particularly in complex maneuvers, but can be computationally intensive. This comparative analysis provides crucial insights for researchers and practitioners in the UAV domain, highlighting the importance of selecting the appropriate control strategy based on mission requirements. By integrating GWO into the optimization process, we pave the way for more efficient and reliable UAV control systems, ultimately contributing to the advancement of autonomous aerial operations. The findings underscore the potential for future work to explore hybrid control approaches that leverage the strengths of each method, further enhancing UAV capabilities in increasingly complex environments.

sciforum-108206: Elevating mobile robot performance: Metaheuristic optimization of PID control for linear speed and angular position

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This article presents a comprehensive study on the control of linear speed and angular position in mobile robots using Proportional-Integral-Derivative (PID) controllers, with a focus on optimizing PID gains through metaheuristic optimization techniques. We begin by developing a detailed mathematical model of the robotic system, capturing its dynamics and response characteristics. Utilizing metaheuristic algorithms, such as Genetic Algorithms and Particle Swarm Optimization, we adaptively tune the PID parameters to enhance system performance in varying operational environments. The simulation results demonstrate significant improvements in trajectory tracking accuracy, reduced overshoot, and quicker settling times compared to conventional PID approaches. Additionally, the optimized PID controller showcases robust performance under different conditions, validating the effectiveness of our modeling and optimization strategy. This research not only highlights the potential of metaheuristic methods in fine-tuning PID controllers but also provides valuable insights into the simulation of mobile robotic systems, contributing to advancements in robotic control and navigation technologies.

Session 4. Remarkable Actuator Applications

sciforum-104747: Non-invasive, non-blood-contact, pneumatic ventricular assist actuator based on wireless energy supply technology

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1. Introduction

When heart function is impaired by 30%-50%, noticeable heart failure symptoms can occur. For end-stage heart failure patients, current ventricular assist devices can achieve a flow rate of 3-6 L/min, but invasive implantation methods pose significant risks of thrombosis and infection [1]. Research on non-blood-contact ventricular assist devices, both domestically and internationally, has mainly focused on pneumatic or hydraulic methods [2]. Although these methods can generate high pressures, they do not achieve non-blood-contact within the body. To improve existing ventricular assist devices, this study has preliminarily designed a wireless-powered pneumatic ventricular assist device. The device replaces percutaneous cable energy supply with magnetic resonance wireless energy technology, non-invasive is realized. It uses an internal gasbag to compress the ventricle, achieving non-blood-contact assistance. This approach offers a potential new technological pathway for the treatment of heart failure, but further research and validation are needed.

2. Methods

The pneumatic ventricular assist actuator mainly consists of an external power source, a wireless energy supply unit, a control system, and the actuator. The wireless energy supply unit provides energy to the internal control circuitry and compression actuator, thereby achieving non-invasive and minimizing the risk of secondary infection. The assist actuator is composed of a microcontroller, an air pump, an air storage gasbag, and a compression gasbag. The microcontroller manages the intake and exhaust pumps to control the expansion and contraction of the gasbag, thereby compressing the heart and achieving non-blood-contact assistance.

3. Results

A hollow silicone heart with a Young's modulus similar to that of the human heart was used as the test object to evaluate the assistive compression capability of the actuator at different compression frequencies. The results showed that the actuator could achieve an assistive compression pressure of 2 kPa at human heart rates (60-120 beats/min), meeting 74% of the required assistive pressure for the human heart. After extended testing, the assistive effect showed only a 3.33% reduction, indicating that the actuator can operate effectively for long periods.

4. Conclusion

The pneumatic ventricular assist actuator proposed in this study achieves non-invasive and non-blood-contact assistance, avoiding the thrombus and infection issues associated with traditional heart pumps. Preliminary experimental results indicate that the device can provide long-term, effective ventricular assistance in simulated human environments. However, the device is still in the early stages of exploration and requires further research and validation. It holds potential to become a viable technological pathway for the treatment of heart failure in the future.

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sciforum-100031: A Multilayer Piezoelectric Thermo-Magnetic Film Generator

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This paper presents the design, fabrication and characterization of a thermo-magnetic film generator for efficient conversion of low-grade thermal energy into mechanical energy and an additional piezoelectric layer to convert the mechanical into electrical energy. Harnessing the abundant waste heat available at low temperatures holds immense potential to power off-grid electronics, such as IoT systems and wearable medical devices. In previous work, we introduced a new class of thermo-magnetic film-based generators (TMGs) for conversion of low-grade thermal energy consisting of movable cantilevers oscillating in resonant self-actuation mode, which boosts power output up to 50 μW/cm^2 while relative efficiencies can reach up to 5% even at temperature difference below 10 K [1]. Based on the concept of resonant self-actuation, we explore the option of converting the mechanical energy of oscillation into electrical energy using an additional piezoelectric layer. Compared to inductive energy conversion, this approach enables an increased voltage output, which can be rectified and stored by standard electronic components.

As shown in Figure 1 (a), the initial part of the cantilever is designed as a three-layer system consisting of brass, epoxy and a piezoelectric layer. The piezoelectric layer is fabricated from 100 μm thick bulk PZT and thinned down to 30 μm by mechanical grinding. The cantilever onset is rigidly clamped to a substrate. Two films made from the magnetic shape-memory-alloy Ni-Mn-Ga of 10 μm thickness are stacked and bonded, then attached to the end part of the cantilever and positioned beneath a magnet, which also serves as a heat source. A finite element model and an analytic model based on Bernoulli's theory are used to design the piezoelectric layer and optimize its power density.

In ferromagnetic state below the Curie temperature (T_C), the Ni-Mn-Ga film is attracted by the magnet. While in solid-solid contact with the heated magnet, it heats above T_C and becomes paramagnetic. Therefore, the magnetic attraction force strongly decreases allowing the elastic forces of the cantilever to reset the initial deflection. As the film cools down below T_C, it transforms back to its ferromagnetic state and the cycle begins anew.

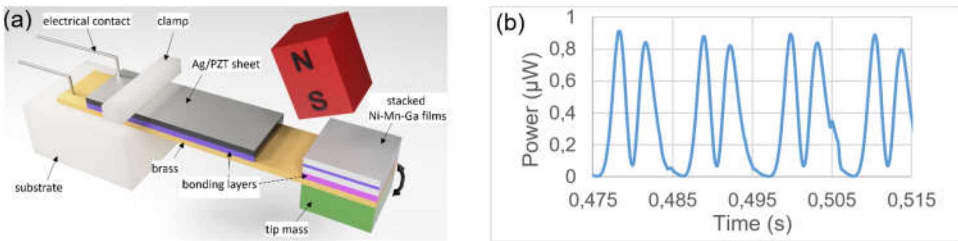

Figure 1. (a) Schematic of the multilayer piezoelectric thermo-magnetic film generator. (b) Power output of the generator device operating in resonant self-actuation mode.

In this work, we demonstrate resonant self-actuation of the hybrid piezoelectric thermo-magnetic film generator by fine-tuning the oscillation frequency of the cantilever to achieve a sufficient temperature change during solid-solid contact with the heated magnet. Due to the epoxy and PZT layers, the thermal behavior of the system is altered, changing the conditions needed for resonant self-actuation. These changes are compensated by reducing the length of the piezoelectric layer and increasing the surface of the brass layer for enhanced convection. Characterization of a cantilever reveals peak output values of 1.5 V and 17 μA at a stroke of 1 mm and a frequency of 100 Hz. With a compact footprint of 0.2 cm^2, this results in a peak power density of 38 $\mu W/cm^2$. As shown in Figure 1 (b), the peak power output of a demonstrator device is 0.9 μW.

These preliminary performance results underline the potential of the concept of resonance self-actuation. In particular, the achieved electrical output facilitates the development of a power management system for energy use.

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sciforum-100141: Adaptive Deployable Polymer Reflector for CubeSats

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The presentation will report on the Advanced Multilayer Adaptive Thin Shell (AMATS) project aimed at developing actively controlled deployable primary reflectors with collecting area significantly larger than the size of the satellite. The project, supported by the ESA GSTP program, involves MateriaNova (Mons, Belgium) and Universite Libre de Bruxelles (ULB). By utilizing a flexible polymer substrate material with an integrated piezoelectric polymer control layer, the reflector can be folded into a small space while using active control to compensate for thermal, viscoelastic and manufacturing errors. The targeted applications are in the Long Wave Infrared (LWIR, λ = 10µm) which is gaining interest for Earth observation, astronomical applications, and up- and downlink laser satellite communication (because data transmission under adverse weather conditions is possible in LWIR). These applications would benefit enormously from the increase of the reflector size while the surface figure accuracy for LWIR seems to be achievable with active control. The project builds on a previous demonstration of the control of a spherical thin polymer shell using a piezoelectric polymer (PVDF-TrFE) activated by an array of independent electrodes on the back side of the reflector. In the AMATS project, the design has been improved by the addition of a thermal balancing layer, and the geometry is being adapted to a petal-design suitable for folding into a 3U CubeSat. The presentation will report on: 1. Progress in manufacturing of the petal polymer reflector. 2. The thermal response of the reflector. 3. The recent developments of a metrology system adapted to the in-lab measurements of the surface figure of a petal spherical reflector with large aberrations, an extension of the Software Configurable Optical Testing System (SCOTS) initially developed in the University of Arizona. 4. The numerical simulation of the folding-deployment phases, the estimation of viscoelas- tic aberration and their control.

sciforum-099389: An electric linear actuator-based lysimeter soil retriever design: Performance optimization and performance loss measurement

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A lysimeter-soil retriever (LSR) is a device that facilitates the efficient and non-disruptive retrieval of soil from lysimeters, streamlining the sampling of intact soil layers. This tool proves particularly advantageous when sampling a substantial quantity of lysimeters, as it simplifies and accelerates the process. Existing LSR designs are complex and better suited for large monolithic field lysimeters. However, these designs are unnecessary for retrieving soil from mini or small lysimeters. Therefore, a simple LSR was fabricated using a linear actuator to retrieve soil from mini or small lysimeters. This paper focuses on the optimization of voltage applied to a linear actuator to control the incremental stopping of soil blocks at heights of 5 and 10 cm. Additionally, performance loss measurements were conducted after soil retrieval from 80 lysimeters. To optimize speed, voltages ranging from 24 to 19 V were applied, and the linear actuator speed and soil block heights were measured. The maximum force and time required to complete a full stroke were also measured before and after the retrieval of 80 lysimeters to assess performance loss. The results showed a linear decrease in linear actuator speed with increasing voltage. Additionally, there was a significant (P0.05) increase in soil block heights as the voltage increased. The desired soil block heights were achieved at 19 V, corresponding to an actuator speed of 11.6 mm/s. Therefore, 19 V was determined to be the optimum voltage for this study. Furthermore, after the retrieval of 80 lysimeters, there were no significant changes in the maximum force and time required for a full stroke, which were recorded as 43 s and 530 N, respectively. These findings demonstrate that the linear actuator is a suitable alternative to a hydraulic piston as a force applicator in the LSR design.

sciforum-104623: Assessing the Impact of Force Feedback in Musical Knobs on Performance and User Experience

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This paper examined how rotary force feedback in knobs can enhance control over musical techniques, focusing on both performance and user experience. To support our study, we developed the Bend-aid system, a web-based sequencer with pre-designed haptic modes for pitch modulation, integrated with TorqueTuner, a rotary haptic device that controls pitch through programmable haptic effects. Then, twenty musically trained participants evaluated three haptic modes (No-force feedback (No-FF), Spring, and Detent) by performing a vibrato mimicry task, rating their experience on a Likert scale, and providing qualitative feedback in post-experiment interviews. The study assessed objective performance metrics (Pitch Error and Pitch Deviation) and subjective user experience ratings (Comfort, Ease of Control, and Helpfulness) of each haptic mode. User experience results showed that participants found force feedback helpful. Performance results showed that the Detent mode significantly improved pitch accuracy and vibrato stability compared to No-FF, while the Spring mode did not show a similar improvement. Post-experiment interviews showed preferences for Spring and Detent modes varied and people provide suggestions for future knob designs. These findings suggest that force feedback may enhance both control and the experience of control in rotary knobs, with potential applications for more nuanced control in DMIs.

sciforum-100039: Basic Driving Characteristics of 2-DOF Soft Mechanism

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In recent years, cord-shaped soft mechanisms have been studied for medical and pipe-inspection applications due to their features such as safety and shape applicability. Some of these mechanisms use actuators based on McKibben-type artificial muscles [1][2]. The artificial muscle consists of a rubber tube and fibers forming a sleeve; half of the fibers are arranged spirally in a clockwise direction, and the other half in a counterclockwise direction. When air pressure is applied, the actuator expands and contracts in the axial direction. Additionally, by arranging a restraining material axially, a curved actuator is created, and by removing the fibers in either the clockwise or counterclockwise direction, a torsional actuator is fabricated. By combining these actuators with different motions in series, soft mechanisms with multiple degrees of freedom (DOF) can be realized. However, the manufacturing process is complex because each actuator is generally manufactured individually and then combined manually.

In this study, we propose a simple fabrication method of soft mechanisms that uses a braider machine. The braider machine has multiple bobbins with fibers set in them. Half of the bobbins rotate clockwise, and the other half rotate counterclockwise, crossing each other. In the center of the machine, the fibers are braided into a helical shape. Therefore, a McKibben-type artificial muscle is realized by setting a rubber tube in the center and driving the machine. The braider machine can also composite fibers in the axial direction, making it possible to realize a curved-type artificial muscle.

In this report, we fabricated a 2-DOF soft mechanism with combined twisting and curving motions. For realizing it, half of the fibers on bobbins are water-soluble fibers, and the other half of fibers are non-soluble fibers, and one plastic fiber is set for restricting material axially. By driving the braider, the rubber tube is covered with them. Twisting part can be realized by solving the water-soluble fibers by soaking them in water and removing the plastic fiber. On the other hand, for the curving part, no procedure needs.

The fabricated soft mechanism has a diameter of 5 mm and a total length of 105 mm, with 33.7 mm dedicated to a twisting part and 71.3 mm to a curving part. Basic experiments have shown that the developed soft mechanism enables independent movement of each part. The maximum twisting and curving angles are 350°and 100°at 300kPa of pneumatic pressure.

We realized the simple fabrication process of cord-shaped soft mechanisms by using the braider, and 2 DOF soft mechanism with twisting motion and curving motion was fabricated. We have plan to apply the mechanism to the medical endoscope in the future.

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Acknowledgments

This study was partly supported by JKA through its promotion funds from KEIRIN RACE.

sciforum-100061: Controlled Deployment of Polymeric Composite Hinges for Space Applications

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1. Introduction

Solar panels are essential components of satellites that harvest solar energy as a source of power to support their operation. Due to their thin shapes and relatively complex and intricate structure, solar panels need to be folded in such a way as to enable a safe and simple launching procedure without causing any damage or harm to the panels. Then, they unfold when the satellite reaches in space.

This research concerns the application of a thermoplastic polymer by incorporating it into the elastic hinge as an actuator to facilitate the unfolding process of the panels with minimal impact. The field of smart or responsive materials has been growing rapidly day by day in recent decades. Researchers can now fabricate structures that can respond to external mediums or stimuli, like temperature, pressure, electric current, heat, humidity, and light, in many interesting ways [1]. These fabricated structures using smart materials can act as sensors and actuators, are self-repairable, or change shape on demand.

2. Materials and methods

The polymeric composite investigated in this research includes the thermoplastic polymer (thermoplastic polyurethane, TPU) as a matrix and carbon fibers as reinforcement to facilitate joule heating. The heating-responsive shape memory effect in this thermoplastic polymeric composite was used to perform the deployment of the hinge in a controlled manner. To demonstrate the deployment of the solar panels in a space satellite and the unfolding of a hinge, an experimental setup was created, as shown in Figure 1. The polymeric composite was attached to the metallic measurement tape, and an electric current was used to stimulate its recovery to its initial shape.

The mechanical properties of TPU, elastic cloth, and composite were characterized using the uniaxial tensile test on a Shimadzu 10 kN UTM with a constant strain rate of 10^{-3} s^{-1}. The Differential Scanning Calorimetry (DSC Model Q200) technique was used to study the melting of TPU and the glass transition temperature.

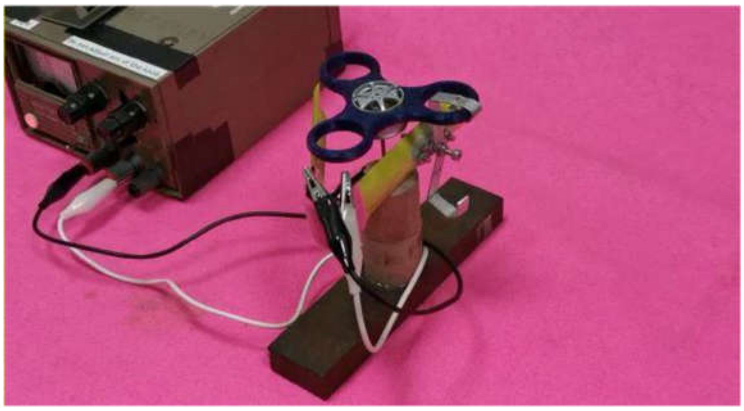

Figure 1. Experimental setup to demonstrate the controlled deployment of polymeric composite hinges.

3. Results and discussion

The mechanical properties of the polymeric composite obtained by the tensile test lie in between those of TPU and elastic cloth. The DSC graph (heat flow vs. temperature) of TPU 265A reveals the following thermal properties:

The TPU 265A begins to melt at nearly 50 °C.

The melting peak temperature (T_m) is 57.32 °C.

The crystallization begins at a temperature of approximately 23 °C.

The crystallization peak temperature (T_P) is 18.88 °C.

The measuring tape was bent at 180° into two equal lengths and then released to its natural position without applying any force. The bent tape acts as a hinge. After performing the rotation of the hinge 10 times, the average number of rotations the ball bearing made from its starting position to its final position was recorded. The results showed that the rotation without the application of polymeric composite at the hinge was significantly higher (630° rotation) than that with the application of polymeric composite at the hinge with the electric power supply, which was 1-2° rotation.

4. Conclusions

Through this research, experimental research was performed to investigate the optimal operating conditions and demonstrate the feasibility of achieving minimal impact during unfolding. The application of the TPU to a recyclable deployment hinge is possible. It can be heated and cooled multiple times without degrading its properties. The temperature required to become soft and viscous is not too high (around 50 °C). Moreover, it is light in weight, easy to manipulate, and less costly than the other materials.

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sciforum-100395: Investigation on the Use of different kinds of Winglets in Unmanned Aerial Vehicles (Drones)

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The speed at which drone technology is developing has led to an infinite stream of ideas for enhancing drone effectiveness. Drone combat performance may be greatly enhanced by lowering the resistance to air. Vortex motion and turbulence are managed by the winglet. Winglets may now be used on drones to increase flying range and cost-effectiveness due to their extensive use in both military and commercial aircraft. This article focuses on the effects of various winglets on increasing lift and decreasing resistance of small consumer drones since different winglets have varying effects on drone flying performance. Specifically, the wingtip fencing, the double forked scimitar winglets, and the fusion winglet are considered to be the three exemplary winglets that serve as the specialized study objects.A thorough introduction is given to the designs for structures and aerodynamic properties. A brief explanation of the role that winglets play in enhancing aircraft effectiveness, conserving energy, and protecting the environment is provided. This article might serve as a guide for drone design. By precisely controlling circulation at the wing edge, the winglet's design and placement may lessen turbulence and the development of vortices, which lowers aerodynamic opposition and increases lift efficacy. Drone applications are going to increasingly rely on the winglet's design and optimization as well as upcoming technological developments. According to wind tunnel testing, the whole vehicle's generated drag can be decreased by 25% to 30%. The drone's increased flying efficiency and effectiveness include lower energy consumption, longer flight times, higher carrying capacities, enhanced agility, and stability thanks to their refined design and the addition of winglets. The use of winglets has accelerated the advancement of drone technology and opened up new avenues for creativity and technological advances in applications for drones down the road. The fusion winglet has a straightforward design, which typically results in cost savings. Fusion winglets are often added to tiny drones to increase performance and decrease design complexity at short ranges.In terms of minimizing drag, the double-fork scimitar winglet performs better than the winglet of fusion type. However, because of production costs, this sort of wingspan may be employed on massive, very resistant drones with wide wing spans without adding to the weight of the fuselage. With an abundance of design freedom, the wingtip barrier may be easily modified to suit changing situations. However, because of the challenging design, wingtip fences tend to raise design and manufacturing costs, so using them in drone design is not advised. The addition of winglets to drones increases the aircraft's range, stability, and energy efficiency. Therefore, it is a useful measure for airliners to enhance the quality of their products.

sciforum-104731: Prototype of film endoscope for narrow environment using textured film actuator and small camera

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In recent years, there has been significant progress in the fabrication of exploration and inspection robots and actuators designed for confined spaces that are inaccessible to humans [1][2]. However, the fabrication process of existing robots and actuators designed for narrow environments is complex. Film actuators offer an effective strategy to address this problem. The structure of film actuators is relatively simple, and they are characterized by a lightweight and thin profile. The use of film actuators in exploration and inspection robots allows for the transportation of a large number of robots simultaneously. Accordingly, we proposed a new robotics concept using film actuators and structures called “Filmotics” [3].

Textured actuator using polyimide film was fabricated in our laboratory. Polyimide film exhibits high environmental resistance and mechanical properties. The actuator is fabricated by simultaneously welding two types of polyimide film and transferring a pattern on the surface. An aluminum foil is deposited on one side of the actuator, and a pattern for electric heating is formed by laser processing. The actuator is heated by applying electrical power to the electrodes and unfolds. The actuator returns to its initial curved state by natural cooling.

In this research, ultra-thin endoscope was fabricated to detect the inside of a narrow environment. The film endoscope is shown in Fig. 1. A small camera is mounted on top of the textured actuator. The endoscope can move through the field of view with one DOF by applying electrical power to the textured actuator. The curvature radius and the generated force of the textured actuator were evaluated when the electric power was applied. Additionally, the camera took pictures of the surrounding conditions while the actuator drove. The dimensions of the fabricated film endoscope are 28 mm × 45 mm, with a maximum protrusion of 4.1 mm and a mass of 85.4 mg. The actuator is constructed from film, it is imperative that the camera does not impede the operation of the actuator drive. The camera was selected based on its diminutive dimensions, minimal weight, and limited number of electrodes for wiring. The dimensions of the camera are 1.1 mm × 1.1 mm × 2.2 mm, and its mass is 4.6 mg. The camera is damaged by high temperatures. Thus, the temperature of the textured actuator surface was monitored for a five-minute interval. The results showed that the elevated temperature generated during actuator operation was not transferred to the camera mounted on the actuator tip. The radius of curvature of the endoscope was 19 mm by applying an electrical power of 1.5 W and a temperature of 216 ℃. The generated force was 20 mN under the same conditions. It is therefore expected to be useful in confined environments.

The endoscope is thin and suitable for confined environments. The direction of bending can be changed by changing the texture pattern. In the future, a multi-degree-of-freedom endoscope will be developed by adding multiple textures.

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