Design and implementation of a dexterous anthropomorphic robotic typing (DART) hand

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Abstract

This paper focuses on design and implementation of a biomimetic dexterous humanoid hand. Several design rules are proposed to retain human form and functionality in a robotic hand while overcoming the difficulty of actuation within a confined geometry. Size and weight have been optimized in order to achieve human-like performance with the prime objective of typing on a computer keyboard. Each finger has four joints and three degrees of freedom (DOF) while the thumb has an additional degree of freedom necessary for manipulating small objects. The hand consists of 16 servo motors dedicated to finger motion and three motors for wrist motion. A closed-loop kinematic control scheme utilizing the Denavit–Hartenberg convention for spatial joint positioning was implemented. Servo motors housed in the forearm act as an origin for wires to travel to their insertion points in the hand. The dexterity of the DART hand was measured by quantifying functionality and typing speed on a standard keyboard. The typing speed of a single DART hand was found to be 20 words min\(^{-1}\). In comparison, the average human has a typing speed of 33 words min\(^{-1}\) with two hands.

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Design and verification of a smart wing for an extreme-agility micro-air-vehicle

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Abstract
A special class of fixed-wing micro-air-vehicle (MAV) is currently being designed to fly and hover to provide range superiority as well as being able to hover through a flight maneuver known as prop-hanging to accomplish a variety of surveillance missions. The hover maneuver requires roll control of the wing through differential aileron deflection but a conventional system contributes significantly to the gross weight and complexity of a MAV. Therefore, it is advantageous to use smart structure approaches with active materials to design a lightweight, robust wing for the MAV. The proposed smart wing consists of an active trailing edge flap integrated with bimorph actuators with piezoceramic fibers. Actuation is enhanced by preloading the bimorph actuators with a compressive axial load. The preload is exerted on the actuators through a passive latex or electroactive polymer (EAP) skin that wraps around the airfoil. An EAP skin would further enhance the actuation by providing an electrostatic effect of the dielectric polymer to increase the deflection.

Analytical modeling as well as finite element analysis show that the proposed concept could achieve the target bi-directional deflection of 30° in typical flight conditions. Several bimorph actuators were manufactured and an experimental setup was designed to measure the static and dynamic deflections. The experimental results validated the analytical technique and finite element models, which have been further used to predict the performance of the smart wing design for a MAV.

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Experimental Duffing oscillator for broadband piezoelectric energy harvesting

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Abstract
This paper presents an experimental piezoelectric energy harvester exhibiting strong mechanical nonlinear behavior. Vibration energy harvesters are usually resonant mechanical systems working at resonance. The resulting mechanical amplification gives an output power multiplied by the mechanical quality factor $Q$ when compared to non-resonant systems, provided that the electromechanical coupling $k^2$ is high as well as the mechanical quality factor $Q$. However, increasing the $Q$ value results in a narrowband energy harvester, and the main drawback is the difficulty of matching a given vibration frequency range to the energy harvester’s resonance frequency. Mechanical nonlinear stiffness results in a distortion of the resonance peak that may lead to a broadband energy harvesting capability while keeping a large output power as for high $Q$ systems. This paper is devoted to an experimental study of a Duffing oscillator exhibiting piezoelectric electromechanical coupling. A nonlinear electromechanical model is first presented including piezoelectric coupling, a nonlinear stiffness as for a Duffing oscillator, and an additional nonlinear loss term. Under harmonic excitation, it is shown that for a particular excitation range, the power frequency bandwidth is multiplied by a factor of 5.45 whereas the output power is decreased by a factor of 2.4. In addition, when compared to a linear system exhibiting the same power bandwidth as for the nonlinear one (which is here 7.75%), the output power is increased by a factor of 16.5. Harmonic study is, however, partially irrelevant, because Duffing oscillators exhibit a frequency range where two stable harmonic solutions are possible. When excited with sine bursts or colored noise, the oscillator remains most of the time at the lowest solution. In this paper, we present a technique—called fast burst perturbation—which consists of a fast voltage burst applied to the piezoelectric element. It is then shown that the resonator may jump from the low solution to the high solution at a very small energy cost. Time-domain solution of the model is presented to support experimental data.

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Morphing unmanned aerial vehicles

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Abstract
Research on aircraft morphing has exploded in recent years. The motivation and driving force behind this has been to find new and novel ways to increase the capabilities of aircraft. Materials advancements have helped to increase possibilities with respect to actuation and, hence, a diversity of concepts and unimagined capabilities. The expanded role of unmanned aerial vehicles (UAVs) has provided an ideal platform for exploring these emergent morphing concepts since at this scale a greater amount of risk can be taken, as well as having more manageable fabrication and cost requirements. This review focuses on presenting the role UAVs have in morphing research by giving an overview of the UAV morphing concepts, designs, and technologies described in the literature. A presentation of quantitative information as well as a
A discussion of technical issues is given where possible to begin gaining some insight into the overall assessment and performance of these technologies.

The experimental validation of a new energy harvesting system based on the wake galloping phenomenon

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Abstract
In this paper, a new energy harvesting system based on wind energy is investigated. To this end, the characteristics and mechanisms of various aerodynamic instability phenomena are first examined and the most appropriate one (i.e. wake galloping) is selected. Then, a wind tunnel test is carried out in order to understand the occurrence conditions of the wake galloping phenomenon more clearly. Based on the test results, a prototype electromagnetic energy harvesting device is designed and manufactured. The effectiveness of the proposed energy harvesting system is extensively examined via a series of wind tunnel tests with the prototype device. Test results show that electricity of about 370 mW can be generated under a wind speed of 4.5 m s⁻¹ by the proposed energy harvesting device. The generated power can easily be increased by simply increasing the number of electromagnetic parts in a vibrating structure. Also, the possibility of civil engineering applications is discussed. It is concluded from the test results and discussion that the proposed device is an efficient, economic and reliable energy harvesting system and could be applied to civil engineering structures.

Mechanical properties of tracheal tubes in the American cockroach (Periplaneta americana)

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Abstract
Insects breathe using an extensive network of flexible air-filled tubes. In some species, the rapid collapse and reinflation of these tubes is used to drive convective airflow, a system that may have bio-inspired engineering applications. The mechanical behavior of these tracheal tubes is critical to understanding how they function in this deformation process. Here, we performed quasi-static tensile tests on ring sections of the main thoracic tracheal trunks from the American cockroach (Periplaneta americana) to determine the tracheal mechanical properties in the radial direction. The experimental findings indicate that the stress–strain relationships of these tracheal tubes exhibit some nonlinearities. The elastic modulus of the linear region of the stress–strain curves was found to be 1660 ± 512 MPa. The ultimate tensile strength, ultimate strain and toughness were found to be 23.7 ± 7.33 MPa, 2.0 ± 0.7% and 0.207 ± 0.153 MJ m⁻³, respectively. This study is the first experimental quantification of insect tracheal tissue, and represents a necessary step toward understanding the mechanical role of tracheal tubes in insect respiration.
A self-repairing polymer waveguide sensor

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Abstract

This paper presents experimental demonstrations of a self-repairing strain sensor waveguide created by self-writing in a photopolymerizable resin system. The sensor is fabricated between two multi-mode optical fibers via lightwaves in the ultraviolet (UV) wavelength range and operates as a sensor through the UV wavelength range. After failure of the sensor occurs due to loading, the interrogation of the power transmitted through the waveguide in the infrared (IR) wavelength range and operates as a sensor through the UV wavelength range.

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Microscope images of final waveguide geometry for five different sensors. Spacing between two silica fibers is 500 μm. Waveguide formation was from right to left.

Bioinspiration from fish for smart material design and function

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Abstract

Fish are a potentially rich source of inspiration for the design of smart materials. Fish exemplify the use of flexible materials to generate forces during locomotion, and a hallmark of fish functional design is the use of body and fin deformation to power propulsion and maneuvering. As a result of nearly 500 million years of evolutionary experimentation, fish design has a number of interesting features of note to materials engineers. In this paper we first provide a brief general overview of some key features of the mechanical design of fish, and then focus on two key properties of fish: the bilaminar mechanical design of bony fish fin rays that allows active muscular control of curvature, and the role of body flexibility in propulsion. After describing the anatomy of bony fish fin rays, we provide new data on their mechanical properties. Three-point bending tests and measurement of force inputs to and outputs from the fin rays show that these fin rays are effective displacement transducers. Fin rays in different regions of the fin differ considerably in their material properties, and in the curvature produced by displacement of one of the two fin ray halves. The mean modulus for the proximal (basal) region of the fin rays was 1.34 GPa, but this varied from 0.24 to 3.7 GPa for different fin rays. The distal fin region was less stiff, and moduli for the different fin rays measured varied from 0.11 to 0.67 GPa. These data are similar to those for human tendons (modulus around 0.5 GPa). Analysis of propulsion using flexible foils controlled using a robotic flapping device allows investigation of the effect of altering flexural stiffness on swimming speed. Flexible foils with the leading edge moved in a heave show

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a distinct peak in propulsive performance, while the addition of pitch input produces a broad plateau where the swimming speed is relatively unaffected by the flexural stiffness. Our understanding of the material design of fish and the control of tissue stiffness is still in its infancy, and the development of smart materials to assist in investigating the active control of stiffness and in the construction of robotic fish-like devices is a key challenge for the near future.

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Dorsal fin of a bluegill sunfish (Lepomis macrochirus) showing the anterior region of the dorsal fin where a thin collagenous membrane is supported by fin spines composed of bone (stained red with Alizarin). Bone elements within the fish body that support the dorsal fin spines are revealed by clearing muscle tissue with trypsin.

Smart film actuators using biomass plastic

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Abstract

This paper presents a novel smart film actuator based on the use of a biomass plastic as a piezoelectric film. Conventional polymeric smart sensors and actuators have been based upon synthetic piezoelectric polymer films such as PVD. Almost all synthetic polymers are made from nearly depleted oil resources. In addition combustion of their materials releases carbon dioxide, thereby contributing to global warming. Thus at least two important sustainability principles are violated when employing synthetic polymers: avoiding depletable resources and avoiding ecosystem destruction. To overcome such problems, industrial plastic products made from synthetic polymers were developed to replace oil-based plastics with biomass plastics. This paper applies a biomass plastic with piezoelectricity such as poly-L-lactic acid (PLLA). As a result, PLLA film becomes a distributed parameter actuator per se, hence an environmentally conscious smart film actuator is developed. Firstly, this paper overviews the fundamental properties of piezoelectric synthetic polymers and biopolymers. The concept of carbon neutrality using biopolymers is mentioned. Then a two-dimensional modal actuator for exciting a specific structural mode is proposed. Furthermore, a biomass plastic-based cantilever beam with the capability of modal actuation is developed, the validity of the proposed smart film actuator based upon a biomass plastic being analytically as well as experimentally verified.

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Shape memory polymer cellular solid design for medical applications

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Abstract

Shape memory polymers (SMPs) are an emerging class of active materials whose response can be easily tailored via modifications of the molecular parameters and optimization of the transformation processes. In this work, we originally demonstrated that a correct coupling of polymer transformation processes (co-extrusion with chemical blowing agents, salt co-extrusion/particulate leaching, solvent casting/particulate leaching) and SMPs allows one to obtain porous structures with a broad spectrum of morphological properties resulting in tunable thermo-mechanical and shape recovery properties. Such a wide range of properties could fulfil the specifications of medical applications in which the use of SMP-based foams can be envisaged.

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SEM micrographs of MM4520 porous structures obtained via solvent casting/particulate leaching. Gelatine sphere ø = 150–400 μm porous structures (a) before and (b) after leaching in water. Gelatine sphere ø = 150–400 μm porous structures (c) before and (d) after leaching in water. Scale bar 500 μm.
Magnetorheological fluid dampers: a review of parametric modelling

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Abstract
Due to the inherent nonlinear nature of magnetorheological (MR) dampers, one of the challenging aspects for developing and utilizing these devices to achieve high performance is the development of models that can accurately describe their unique characteristics. In this review, the characteristics of MR dampers are summarized according to the measured responses under different conditions. On these bases, the considerations and methods of the parametric dynamic modelling for MR dampers are given and the state-of-the-art parametric dynamic modelling, identification and validation techniques for MR dampers are reviewed. In the past two decades, the models for MR dampers have been focused on how to improve the modelling accuracy. Although the force–displacement behaviour is well represented by most of the proposed dynamic models for MR dampers, no simple parametric models with high accuracy for MR dampers can be found. In addition, the parametric dynamic models for MR dampers with on-line updating ability and the inverse parametric models for MR dampers are scarcely explored. Moreover, whether one dynamic model for MR dampers can portray the force–displacement and force–velocity behaviour is not only determined by the dynamic model itself but also determined by the identification method.

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Working principle of bio-inspired shape memory alloy composite actuators

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Abstract
Recently, bio-inspired shape memory alloy composite (BISMAC) actuators have been shown to mimic the deformation characteristics of natural jellyfish medusas. In this study, a constant cross-section BISMAC actuator was characterized in terms of bending deflection and force in conjunction with microscopy to understand its deformation mechanism. The actuator showed bending deflection of 111% with respect to the active length along with a blocking force of 0.061 N. The resulting energy density of the composite actuator was 4929 J m⁻³ at an input voltage and current level of 12 V and 0.7 A, respectively. For a dry-state actuator, this performance is extremely high and represents an optimum combination of force and deflection. Experiments reveal that BISMAC’s performance is related to the moment induced from tip attachment of the shape memory alloy (SMA) rather than to friction within the composite structure. A physics-based model of BISMAC structure is presented which shows that the actuator is highly sensitive to the distance between the SMA wire and the incompressible component. While SMA has both stress and strain limitations, the limiting factor in BISMAC actuators is dependent on separation distance. The limiting factor in BISMAC’s suitability for mimicking the performance of medusa was experimentally found to be related to the maximum 4% strain of the SMA and not its force generation.

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Polymer optical fiber sensors—a review

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Abstract
Polymer optical fibers (POFs) have significant advantages for many sensing applications, including high elastic strain limits, high fracture toughness, high flexibility in bending, high sensitivity to strain and potential negative thermo-optic coefficients. The recent emergence of single-mode POFs has enabled high precision, large deformation optical fiber sensors. This article describes recent advances in both multi-mode and single-mode POF based strain and temperature sensors. The mechanical and optical properties of POFs relevant to strain and temperature applications are first summarized. POFs considered include multi-mode POFs, solid core single-mode POFs and microstructured single-mode POFs. Practical methods for applying POF sensors, including connecting and embedding sensors in structural materials, are also described. Recent demonstrations of multi-mode POF sensors in structural applications based on new interrogation methods, including backscattering and time-of-flight measurements, are outlined. The phase–displacement relation of a single-mode POF undergoing large deformation is presented to build a fundamental understanding of the response of single-mode POF sensors. Finally, this article highlights recent single-mode POF based sensors based on polymer fiber Bragg gratings and microstructured POFs.

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The state of understanding of ionic polymer metal composite architecture: a review

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Abstract
Ionic polymer metal composites (IPMCs) are electroactive polymers (EAPs) that are used as soft actuators and sensors. Various mechanical or chemical manufacturing techniques, used for manufacturing IPMC, impart a layered structure that plays a significant role in transduction. These layers comprise of the polymer that constitutes the bulk of the IPMC (polymer layer), the metal used for electroding (electrode layer) and the composite consisting of dispersed metal particles in the polymer matrix (intermediate layer). While ionic pendant chains in the polymer layer are responsible for the charge transport in IPMCs, the metal particles in the intermediate and electrode layers act as conductive pathways for current transmission. At the same time the layered structure imparts a capacitive nature to the IPMC, which positively affects the ionic transduction in the IPMC. The role of each layer and the coupling between them is important for improving IPMC properties and, hence, transduction. The aim of this article is to review the research conducted on IPMC fabrication and layered architecture and study their role in IPMC transduction.

Impact damage resistance and damage suppression properties of shape memory alloys in hybrid composites—a review

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Abstract
Composite materials are known to have a poor resistance to through-the-thickness impact loading. There are various methods for improving their impact damage tolerance, such as fiber toughening, matrix toughening, interface toughening, through-the-thickness reinforcements, and selective interlayers and hybrids. Hybrid composites with improved impact resistance are particularly useful in military and commercial civil applications. Hybridizing composites using shape memory alloys (SMA) is one solution since SMA materials can absorb the energy of the impact through superelastic deformation or recovery stress, reducing the effects of the impact on the composite structure. The SMA material may be embedded in the hybrid composites (SMAHC) in many different forms and also the characteristics of the fiber reinforcements may vary, such as SMA wires in woven laminates or SMA foils in unidirectional laminates, only to cite two examples. We will review the state of the art of SMAHC for the purpose of damage suppression. Both the active and passive damage suppression mechanisms will be considered.

A tailless timing belt climbing platform utilizing dry adhesives with mushroom caps

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Abstract
In many instances, a climbing robot that utilizes dry adhesives as an attachment method may be found to be very useful due to the inherent nature of biomimetic fibrillar dry adhesives in the applications of space, security, surveillance and nuclear reactor cleaning and maintenance. In this paper, a novel tank-like modular robot is developed that does not require a tail to provide a preload to the front of the robot while climbing. Biomimetic fibrillar dry adhesives with mushroom caps manufactured into belts are used as an attachment method. The manufacturing of the dry adhesive belts is discussed and the adhesion properties are examined. The timing belt based climbing platform (TBCP-II) utilizes two tank-like modules connected with an active joint with continual surface–robot distance measuring providing feedback for active adhesive preloading. The mechanical, electronic and software design is discussed. Reliable vertical surface climbing is achieved and the preloading strategy and response is examined. TBCP-II is shown to be capable of both horizontal to vertical and vertical to horizontal surface transfers over both inside and outside corners.
A novel foil actuator using the magnetic shape memory effect

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Abstract
A novel foil actuator of 15 ×3 mm² lateral dimensions is presented making use of the magnetic shape memory (MSM) effect. The actuation material is a Ni–Mn–Ga foil of 200 μm thickness that has been fabricated by cutting of a bulk Ni–Mn–Ga(100) single crystal consisting of 10 M martensite variants at room temperature. Stress–strain experiments on tensile test structures demonstrate that the stress needed for reorientation of martensite variants is about 1.2 MPa. The low twinning stress allows magnetic-field-induced variant switching, the basic mechanism of MSM actuation. A Ni–Mn–Ga foil actuator is fabricated by lithography and hybrid integration. The actuator shows a maximum magneto-strain of 4.9%, which is limited by the constraints of fixation and loading. Upon tensile loading at 1.5 MPa, linear actuation cycles are generated with an actuation stroke of 2.2%. The foil actuator is used as a benchmark system for modelling the coupled magneto–mechanical behavior of MSM actuation. We present finite element simulations based on a thermodynamic Gibbs free-energy model that qualitatively describes the observed tensile stress-dependence of magneto-strain.

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Detecting the delamination location of a beam with a wavelet transform: an experimental study

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Abstract
An experimental study is reported for the location detection of a delamination in a beam structure under a static displacement with a spatial wavelet transform. An invisible perturbation in the deflection profile of the delaminated beam at the two delamination edges owing to the curvature discontinuity is discerned or amplified through a wavelet transform. In this research, two delaminated cantilever beams with different dimensions and materials subjected to a static displacement at their free ends are investigated experimentally. The static profiles of the delaminated beams acquired by a high-precision laser profile sensor are analyzed with the Gabor wavelet to identify the delamination location. Through both the finite element model (FEM) and experimental studies, the detection of the delamination location using spatial wavelet analysis is achieved effectively.

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Plucked piezoelectric bimorphs for knee-joint energy harvesting: modelling and experimental validation

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Abstract
The modern drive towards mobility and wireless devices is motivating intensive research in energy harvesting technologies. To reduce the battery burden on people, we propose the adoption of a frequency up-conversion strategy for a new piezoelectric wearable energy harvester. Frequency up-conversion increases efficiency because the piezoelectric devices are permitted to vibrate at resonance even if the input excitation occurs at much lower frequency. Mechanical plucking-based frequency up-conversion is obtained by deflecting the piezoelectric bimorph via a plectrum, then rapidly releasing it so that it can vibrate unhindered; during the following oscillatory cycles, part of the mechanical energy is converted into electrical energy. In order to guide the design of such a harvester, we have modelled with finite element methods the response and power generation of a piezoelectric bimorph while it is plucked. The model permits the analysis of the effects of the speed of deflection as well as the prediction of the energy produced and its dependence on the electrical load. An experimental rig has been set up to observe the response of the bimorph in the harvester. A PZT-5H bimorph was used for the experiments. Measurements of tip velocity, voltage output and energy dissipated across a resistor are reported. Comparisons of the experimental results with the model predictions are very successful and prove the validity of the model.

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Piezoelectric strain sensor/actuator rosettes

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Abstract
In-plane anisotropy in the linear piezoelectric constitutive law for [011]c cut and poled PMN–0.29PT–0.23PT is demonstrated to enable its use as a sensor/actuator rosette. The equations for a 0°/45°/90° rosette are developed using the conditions of coupling between the in-plane strain of the crystal and a substrate, and zero out-of-plane stress on the crystal (plane stress conditions in the crystals). The crystals are bonded to a substrate aluminum plate that is instrumented with strain gages next to the crystals. The plate is subjected to bending along different axes and the resulting electric displacement change of the crystals is monitored. The strain components calculated using the change of electric displacement are compared with the strain components measured using strain gages. This sensor/actuator rosette approach is demonstrated to enable both sensing principal strain components and actuating principal strains in an electronically controllable direction.

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