International Journal of Intelligent Robotics and Applications (2021) 5:283–286
https://doi.org/10.1007/s41315-021-00202-2

EDITORIAL

Introduction to the focused section on flexible mechatronics for robotics

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Published online: 12 September 2021

Flexible mechatronics have been playing a critical role for intelligent robots in unstructured environments and extreme conditions that needs efficient task performance, adaptability to handle nonlinear behaviors and robustness to unpredictable disturbances. To achieve these goals, robotic systems with compliant mechanical structures and flexible electronic components must be properly designed, where challenges in precise modeling, efficient analysis, smart sensing and actuation, and effective control schemes have attracted broad attention from researchers.

With the emerging applications to robotics, this focused section competitively selects the 10 research papers covering a spectrum of theoretical backgrounds and applications including industrial automation, infrastructure monitoring, wearable technologies, bio-inspired and biomimetic robots. Although boundaries among the papers can depend on multi-metrics, they are categorized from the perspectives to promote flexible mechatronics for intelligent robotics and applications spanning theoretical modeling, system identification and feature recognition, novel control methods for flexible systems, and smart sensing/actuation in promising applications of human-centered and autonomous robots.

1 Theoretical modeling approach

A mathematically trackable model to capture motions of a soft robot is critical to the analysis of actuation mechanism and design of feedback control. The paper entitled "*Modeling of Jellyfish-inspired Robot Enabled by Dielectric Elastomer*" presents a soft jellyfish robot to exhibit contracting muscle-like behavior using dielectric elastomer (DE) diaphragm actuator associated with a transmission mechanism. The DE actuator can provide the compliant thrust force as needed for propelling the jellyfish robot to transit through water noiselessly and efficiently. Theoretical models of the compliant mechanism, DE membrane actuation and water ejection have been rigorously formulated and experimentally validated. High nonlinearity and low computation efficiency of complicated distributed models render great challenges in dynamic analysis and motion control. The paper "*Modeling Spatial Multi-link Flexible Manipulator Arms Based on System Modes*" provides a systematic approach to derive a low-order model for spatial serial flexible robot arms using mode shapes that are defined for the whole structure. Capable to account for the tip-attachment dynamics, motor shaft inertia and torsional effects, the model is still suitable for real time implementation with high fidelity because the dominant modes are reserved in order reduction via modal analysis. The model has been numerically verified with finite element analysis and experimentally validated.

2 Data-driven approach for analysis

In practice when a system is too complicated for quantitative evaluation, data-driven techniques provide a promising way for system identification and feature recognition. In "*Physics*

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Informed Neural Network for Parameter Identification and Boundary Force Estimation of Compliant and Biomechanical Systems", an approximation function to capture boundary conditions is embedded in a physics-informed neural network to solve for the forward and inverse problems in engineering. The method provides a practical alternative overcoming several limitations of traditional perturbation-based models, and its immediate application is illustrated with the ankle-joint study for exoskeleton design. The paper entitled "*Robotics Assisted Smart-Touch Pipeline Inspection*" presents a novel robotic system integrating a lightweight robotic arm on a mobile platform to enable autonomous on-shore pipeline inspection. Object detection with neural networks was performed to detect pipeline flanges, and smart touch sensors were employed for feedback control of bolt looseness inspection. The paper details the robotic system design, smart touch sensing, visual recognition and localization, and control.

3 Novel control with robustness and compliance

In exploring unknown ocean areas with extreme conditions, soft manipulators are competent candidates for non-destructive underwater tasks. The paper "*Prediction Model-based Learning Adaptive Control for Underwater Grasping of a Soft Manipulator*" proposes a prediction model-based guided reinforcement learning adaptive controller (GRLMAC) for a soft manipulator system, whose movements can be easily disturbed by the inherent nonlinearity of soft materials, flow currents, payload variations, and so on. Tests in the pumped flow current and various load conditions showed that the proposed design acquires promising accuracy, robustness, and adaptivity. In "*Design and Hybrid Control of a Two-axis Flexure-based Positioning System*", a hybrid PID-feedback and force feed-forward controller is developed to achieve motion tracking with a high precision on the two-axis compliant positioning system. The controller has properly compensated for the complicated system behavior due to the stiffness nonlinearity and cross-coupling interactions of two axes.

4 Smart sensing and actuation with applications

Two successful applications of flexible mechatronics are illustrated with autonomous robots and human-centered robots. The review paper "*Towards Reconfigurable and Flexible Multirotors: a Literature Survey and Discussion on Potential Challenges*" surveys reconfigurable multirotors (RMs) classified in three categories of tiltrotors, multimodal and foldable RMs, whose platforms are analyzed from different perspectives of mechanical design, challenges of low-level control and high level motion planning techniques. It also presents major challenges in designs and algorithms and discussion on future directions. The paper entitled "*A Compact, Compliant, and Biomimetic Robotic Assistive Glove driven by Twisted String Actuators*" quantifies the performance of twisted string actuators to conventional spooled-motor configurations. The robotic assistive glove has been developed with super coiled polymers for position monitoring and passive actuation. The robotic glove is adaptive to various object sizes and shapes, and it achieves more than 7 N fingertip forces with 186 g in total weight. The research on "*An Efficient Force-Feedback Hand Exoskeleton for Haptic Applications*" shows a wearable exoskeleton capable of delivering sensation to the fingers while interacting with the objects in virtual reality environment. To achieve a compact and ergonomic design, the device is driven by a series elastic actuator mechanism, and the kinematics are captured via the exoskeleton mechanism inspired from the skeletal structures of a human finger. In "*Pressure Monitoring Based Identification of the EOD Suit–human Interface Load Distribution*", a test methodology has been proposed to identify the relationship between explosive ordnance disposal (EOD) suit interface loads and mission-critical performance metrics. This study implements the largest pressure region ever recorded on the human body and is the first of its kind to investigate the movement restriction of personal protective equipment for various practical tasks. Comprehensive experimental findings are obtained based on human tests, including a combination of survey, qualitative observations, and feedback of a test course.

5 Summary and acknowledgement

This focused section disseminates the most recent advances in the field of flexible mechatronics for robotics, addressing issues of modeling, analysis, control, actuation and sensing. Flexible mechatronics is a very broad area that many excellent works have not been covered in this focused section, and we anticipate to witness impressive researches driven by the interdisciplinary thrust of fundamental sciences and emerging technologies in the future.

Finally, we would like to acknowledge the great efforts and contributions by the authors and anonymous reviewers towards this focused section. We would also like to extend our sincere gratitude to the editor-in-chief and outstanding journal staff at IJIRA that made this focused section possible.

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