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Guest Editorial

Special Section: Theory and Design of Reconfigurable Mechanisms and Robots

Advanced robotic systems are expected to be smartly reconfigurable to adapt to new needs for versatile operations in rapidly changing unknown, uncertain environments. The evolution has led to worldwide research interest in developing reconfigurable mechanisms and robots as intelligent-mechanical systems which have the ability to change their mobility, configurations, kinematics, and dynamics performance for various application scenarios in industrial automation, healthcare, space, field exploration, maintenance, domestic operations, human assistance, and augmentation. This Special Section features 14 papers that highlight the latest theories, designs, analyses, and deployments of reconfigurable mechanisms and robots with contributions from papers presented in the IEEE/IFToMM International Conference on Reconfigurable Mechanisms and Robots (ReMAR 2021) [1] as well as an Open Call for Papers.

Mechanism and robot reconfiguration stems from geometric constraint changes based on innovative design and control operation. Systematic design synthesis theory and use-oriented design methodologies are critical to generating more reconfigurable mechanism and robot concepts. Reconfiguration has been extended from basic reconfigurable joints and linkages, to various mechanisms, and to various robot functions including ground mobile motion, flying navigation, manipulation, soft robotics, and sensing interaction. Fundamental modeling and analysis of those newly developed designs are the basis to verify the reconfiguration process and guide application-based development with experimental validation. In this special issue, reconfiguration highlights numerous exemplars in the form of modular manipulators, deployable linkages, reconfigurable grippers, origami mechanisms, and reconfigurable parallel mechanisms with both rigid links and cable-driven designs.

Modular design enables flexible manipulator design and reconfiguration. Ju et al. present a cable-driven manipulator with a lightweight and expandable structure based on a modular U-joint unit for flexible environment adaptability. A fast heuristic inverse kinematics model is developed for the hyper-redundant system and provides a reference solution for other reconfigurable redundant designs. A similar modular cable-driven continuum arm is developed by Sitler and Wang for free-floating underwater manipulation onboard a remotely operated vehicle (ROV). In addition to the flexible arm design based on the modular unit, a reconfigurable dual arm configuration is also realized for crawling gait, dexterous, and seafloor manipulation. Modular units-based serial chain arm could be redundant and self-reconfigurable, requiring intensive dynamic calculations in simulation. To reduce the computational load, Fass et al. present a general novel analytical approach to formulate the Newton–Euler dynamics of self-reconfigurable chains in a single vectorized differential equation which enables efficient parallel computing.

Reconfigurable linkages provide a fundamental basis for mechanism reconfiguration in a wide range of application scenarios. Tang et al. present a novel quadruped robot using a single-loop metamorphic mechanism to enable the ability of transforming between different working modes. This paves the way for developing versatile mobile robots using reconfigurable linkages. By applying Hoberman's linkage as the modular design, Zhang et al. present a snake-inspired swallowing robot that can synchronously deploy and fold both axially and radially. The work creatively demonstrates an application of reconfigurable linkages in bio-inspired robot designs. To match demands of rapid development in the automotive industry, Lyu et al. present a reconfigurable modular fixture with high modularity and flexibility. The design method has a potential in generating more flexible fixture systems in industrial applications with frequent object size changes.

Robot grasping requires high flexibility and adaptability in interacting with objects of various sizes and geometry. Sun et al. propose a reconfigurable robotic gripper based on a metamorphic finger mechanism which can have both expanding and grasping functions. The work expands reconfigurable mechanism applications into robotic grippers aiming at improving object grasping performance. To have an adaptable grasping function, soft materials are applied to gripper designs. However, their grasping force is generally low. To solve this problem, Cheng et al. introduce a limiting fiber into a soft finger design which largely increases the grasping force capacity and bending response speed. The method can be applied to similar soft robotic designs.

Origami designs are a kind of reconfigurable mechanisms based on their folding/unfolding functions. Combining with a hydraulic power source, an origami actuator is developed by Liu et al. and integrated into a 6DOF Stewart-Gough parallel mechanism to realize translational and rotational motions. The design shows potential to be implemented in constructing dexterous and lightweight soft robotic applications. To quantify and improve folding reliability of origami systems, Liu et al. propose a biasing method to model the folding process through the origami hyperbolic paraboloid (hypar) when folding into one of two possible configurations. The results show an increased folding accuracy from 50% to 70% and provide insights for folding reliability analysis in more complex origami patterns with various reconfigurations.

Reconfigurable parallel mechanisms can change their output motion types through constraint singularity, reconfigurable joints, re-assembly, or reconfigurable base/platform and links. The first three methods are demonstrated by three papers in this Special Section. Ye et al. present a new reconfigurable parallel mechanism that can reconfigure into 1R2T and 2R1T operation modes through a constraint singularity when the platform is parallel to the base. Zhao et al. present unified kinematics and dynamics modeling of a n(3RR1S) reconfigurable manipulator based on the principle of recursive virtual power. The work provides a method for solving high-redundant series-parallel systems with reconfigurable parallel modules for potential space object grasping applications. Through module re-assembly, Feng et al. investigate all possible non-isomorphic configurations of a reconfigurable hexapod robot using Pólya enumeration theorem. The method is applicable for other similar reconfigurable robot and mechanism designs using modular combinations.

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Cable-driven parallel robots (CDPRs) with movable anchor points can reconfigure into infinite configurations for flexible manipulation tasks with the anchor points attached to mobile ground or aerial vehicles. To solve their real-time planning, Xiong et al. present a dynamic control method through a reconfiguration value function, which is defined to value possible RCDPR configurations for optimal selection and planning. The developed method creatively treats the planning problem as a reconfiguration model and can be extended to other similar mobile robot planning tasks.

We hope this Special Section will contribute to the research on reconfigurable mechanisms and robots as a key trend in mechanisms and robotics. We would like to show our great thanks to the general chair of ReMAR 2021, Professor Fengfeng Xi, and to the Editor-in-Chief, Professor Venkat Krovi, for his guidance and huge support throughout the whole process. We are also grateful to the journal administrative team and all the authors and reviewers for their valuable support and contributions.

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Reference

[1] Anon, "ReMAR 2021," http://www.remar2021.com/