Guest Editorial
Focused Section on Aerospace Mechatronics

I. Introduction

TREMENDOUS advances are being made in underlying theories, devices used, and systems implemented for a variety of aerospace driven applications involving aeronautical/space vehicles, unmanned aerial vehicles (UAVs), and planetary surface vehicles. Associated with this trend, issues like the system design, modeling, estimation, control, guidance, reliability, fault diagnosis as well as software development receive enhanced attention both in engineering and research domains. The primary objective of this "Focused Section on Aerospace Mechatronics" of the IEEE/ASME Transactions on Mechatronics is to provide a cross section of latest aerospace mechatronics achievements made by researchers and practitioners, and to identify critical issues and challenges for future investigation.

The 11 papers published in this Focused Section contain theoretical and practical or experimental results documenting recent advances in aerospace mechatronics and, in particular, new ideas and approaches in the related fields. The variety of aerospace systems addressed includes the aerospace actuators, air-breathing vehicles, UAVs, thermal wind tunnels, micropropulsion systems, satellites, and planetary rovers. Such variety is indicative of the broad applicability of mechatronics in this domain. Specific research and application topics covered include: model-based estimation; fault detection and diagnosis; microelectromechanical systems (MEMS); complex aircraft control; UAV modeling, control, and haptic teleoperation; wind tunnel temperature control; satellite attitude control; and estimation of terramechanics effects associated with planetary rover trafficability.

II. Aerospace Mechatronics Exemplars

While the papers published in this Focused Section combine to represent a reasonable cross section of the aerospace mechatronics field, many more components, mechanisms, subassemblies, systems, algorithms, and fabrication and manufacturing techniques are being developed to improve and enable new mechatronics advances for aerospace applications. Neither this Editorial nor the overall Focused Section could do justice to adequate coverage of every topic that falls within the scope of aerospace mechatronics. A lucid appreciation for the field can be offered, however, through references to exemplars that represent the essence of mechatronics in aerospace.

Considering current aerospace trends and hot topic application areas, mechatronics for unmanned aerial systems and space robots serve as good examples. Further considering the importance of size, weight, and power for practical aerospace systems, technologies that offer improvements in these attributes are also worthy of mention. In the domain of unmanned aerial systems and vehicles, sensor payloads incorporating sophisticated electrooptical, infrared, and other sensing modalities along with high performance electromechanical pointing and control systems integrated within a single package or compact subassembly are quintessential. Advances in aerodynamics and propulsion mechanisms for fixed-wing, rotary, and lesser conventional vehicles are also noteworthy. Recent publications on various state-of-the-art developments and implementations can be found in [1]–[7].

Mechatronics developments for space robotics systems are persistently challenged by size, weight, power, and the extreme conditions (thermal, radiation, gravitation, etc.) of operational environments encountered on orbit, in space, and on planetary surfaces. Exemplars that benefit from and rely on advances in mechatronics include robotic arms and tools as well as planetary surface systems such as rovers, including their associated mobility, manipulation, sample acquisition, and sample handling systems. Recent publications on various state-of-the-art developments and implementations can be found in [8]–[15].

Technologies that offer improvements in size, weight, and power will address needs for miniaturized mechatronics to enable the current trend toward smaller and smaller satellites, for mechatronic automation enabling more streamlined and agile astronaut spacesuits and more generally, for actuator advancements that improve size-to-weight and power-to-weight ratios. Many recent publications on such topics are available in the literature; examples can be found in [16] and [17].

III. Focused Section Overview

Several papers in this Focused Section address aerospace actuator modeling, fault handling, and control. Gadsden *et al.* apply a new model-based estimation approach to enable fault detection and diagnosis for an experimental electrohydrostatic actuator, a device finding increased use in aerospace systems. The estimators are based on the interactive multiple model strategy combined with a smooth variable structure filter, leading to improvements beyond methods based on popular estimation filter alternatives. Widdis *et al.* describe modeling, fabrication, simulation, and experimentation associated with design and development of a new MEMS-based reactor for a small satellite micropropulsion system. Results and lessons learned from a prototype development and test effort are presented revealing advancements beyond prior prototype developments and focus areas for additional improvement. Magnetic torquer actuation for small satellites is addressed by Zanchetti *et al.* In particular, their paper covers the challenge of projection-based attitude controller design and tuning. Their approach enables robustness to model uncertainty as well as optimal disturbance attenuation,

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revealing superior performance in simulation relative to prior methods. Khan and Nahon present a model for small UAV thrusters, the dynamics of which dominate small UAV motion. The thruster model is based solely on identification of physically measurable system parameters and produces results in close agreement with experimental test results, thus demonstrating impressive model accuracy.

Several papers focus on aircraft control, UAV modeling, and experimentation as well as a controller for a complex aerospace experimental system. Wu *et al*. report a new approach to output tracking control of longitudinal dynamics for flexible hypersonic air-breathing vehicles based on a linear parameter-varying system model. Such vehicles hold promise for enabling routine access to space but are characterized by complex dynamics that challenge controller design. The authors' approach results in a robustly stable, closed-loop controller design validated via simulations. Wang and Inman present models and experiments for evaluating a multifunctional wing spar that enables a small UAV to harvest its own energy during flight and also to control wind gust disturbances. Results reveal the relationship between harvesting time and wind gust duration required to achieve this capability. The problem of fault detection and identification for a small UAV is addressed by Freeman *et al*. from two perspectives, applying a model of UAV dynamics as well as data-driven anomaly detection. Experimental flight test data including nominal and faulted conditions are used to robustly detect different aileron faults. Furthermore, the flight test data generated by the authors' UAV flight research platform are made available via the Internet to the research community. Li *et al*. develop a cascade fuzzy-PID control system for a high-speed, high-airflow wind tunnel for which precise control and robustness are validated experimentally. It addresses challenges associated with the design of a controller with high dynamic range for simultaneous temperature and fuel-oil flow rate regulation within a complex physical and thermal wind tunnel environment.

Finally, three papers cover techniques for addressing problems associated with field applications of UAV and rover systems. The paper by Kim *et al*. addresses the problem of landing small, fixed-wing UAVs using a net-recovery system that does not require a clean runway. The authors employ computer vision-based detection of the net and apply guidance algorithms to enable a fully autonomous UAV recovery system with cost, mass, and complexity advantages relative to alternative solutions. The system and approach are described in detail, net-recovery experiments are reported, and techniques are proposed for improving reliability of vision-based net detection. Lee *et al*. introduce a new framework for single-operator control of the bulk motion of multiple UAVs. The framework enables remote semiautonomous teleoperation with haptic feedback over the Internet. Results from experiments using four quad-rotor UAVs are included which support the underlying theory detailed in the paper. Considering the planetary surface exploration domain, Hegde *et al*. describe a method for estimating sinkage of rover wheels in soft terrain, a perception that would enhance safe operations for rovers navigating in soft and dusty terrain on the surface of the moon. Computer vision and effective image processing techniques are described that improve robustness of sinkage estimation for various illuminations, shadowing, and dust conditions.

The collection of papers in this Focused Section reveals the richness of recent aerospace mechatronics research and is a snapshot of where the field stands today. The results will contribute to continued progress toward understanding and solving essential problems enabling and improving mechatronics implementations in aerospace.

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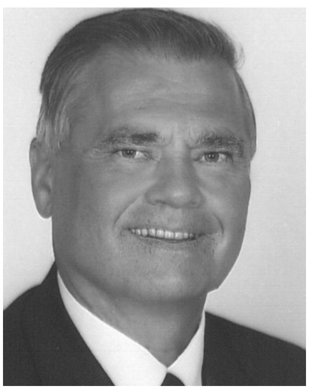

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