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GUEST EDITORIAL

SPECIAL SECTION ON

SOFT COMPUTING FOR SPACE AUTONOMY

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Robotic and human exploration of our solar system requires space missions to be designed with high levels of autonomy for dealing with hostile environments and restricted communication links. Researchers are discovering new solutions to associated problems using fuzzy logic, artificial neural networks, evolutionary computation and probabilistic reasoning, some of the principal elements of soft computing. The uncertainty of space environments and the need for safe mission operations in response to anomalies makes such soft computing techniques good candidates to improve the development of "intelligent autonomous systems" needed for future space missions. This special section provides a representative cross-section of innovative and practical research and applications of Soft Computing for Space Autonomy. The articles offer recent developments in soft computing for robotic applications, computer vision, control, monitoring, and scheduling.

The special section begins with an article by Remy and Howard presenting a methodology that enables a robotic system to interactively learn how to perform tasks from examples provided via teleoperation by an astronaut, mission designer, or engineer. The methodology employs self-organizing maps in the form of neural networks to extend a robot's ability to operate with a competence on par with its human teacher, thus enhancing human-robot interaction potential for space missions. Representative application examples in relevant task scenarios are presented and neuro-controller, classical controller, and human teleoperator task performance are measured and compared.

Massari, Sangiovanni, and Bernelli-Zazzera provide a detailed investigation of properties of a dynamic neural network controller for a six-legged rover prototype designed for rough planetary terrain mobility. The controller is implemented as a continuous-time recurrent neural network designed with the aid of evolutionary algorithms. Effectiveness and robustness of the controller are demonstrated by convincing experimental results in simulation and on a physical rover testbed considering sensor errors and failure as well as perturbations in neural network parameters. Their approach enables soft computing-based dynamical control of multi-degree of freedom systems and achieves excellent results while circumventing more complicated model-based control design methodologies.

The article by Santos et al proposes automatic generation of fuzzy sets for fault monitoring and terrain recognition tasks associated with a drilling system for the ESA ExoMars rover. A novel sensor-driven fuzzy set learning method is proposed as a time-efficient alternative to knowledge engineering via domain experts. Simulated sensing of drill motions is used to infer the type of terrain being drilled which influences terrain-specific drill motor control modes. Fuzzy logic fault monitoring and terrain recognition systems realized using the proposed method are compared to systems realized using an alternative fuzzy set generation technique, demonstrating better inference performance.

Shirkhodaie and Tunstel investigate and compare several soft computing techniques applied to vision-based terrain traversability assessment for safe rover navigation. Spatial geometry and textural appearance derived from terrain surface images are both used to perceive and reason about rover traversability using three assessment methods employing rule-based, neural network, and fuzzy logic techniques. The most promising results were due to the latter two techniques. Each technique is applied to assess actual Mars terrain images from NASA rovers and successfully demonstrated in laboratory experiments of traversability based path planning using a commercial mobile robot.

Various powerful image processing applications of fuzzy logic reasoning and representative results are presented by Dominguez and Klinko for assessing aspects of NASA Space Shuttle safety. Applications include detection and tracking of moving foreign object debris during liftoff, visual anomaly detection in the emergency egress system at the launch pad, and visual detection of distant birds approaching the launch pad. Some of the implementations were augmented with learning capabilities using commercial neural network and genetic algorithm software. The fuzzy reasoning based image analysis methods described in the article were also used to analyze images acquired during the accident of the NASA Space Shuttle Columbia.

Reddy, Homaifar, and Esterline apply genetic algorithms to deal with nonlinear characteristics of spacecraft flight trajectory control with minimum fuel consumption. The research objective is to develop a heuristic process to obtain near-optimal control profiles for an ionic thruster on deep space mission vehicles such as the Jupiter Icy Moons Orbiter. Simulations demonstrate promising results using intermittent low thrusts as well as sensitivity of the genetically evolved control strategy to propulsion system under-performance.

The article by Coelho et al presents a fuzzy inference system design for monitoring the laser gyroscope subsystem on the ESA ROSETTA unmanned space probe. The proof-of-concept study employs fuzzy logic to monitor degradation of laser intensities over the life of the spacecraft's mission. The fault detection tool is intended to generate alarms to facilitate monitoring by the mission operations team. A new fuzzy inference method based on the Choquet integral is applied within a Takagi-Sugeno-Kang fuzzy system and results in faster reactions to alarm conditions than a classical fuzzy system. The proposed laser gyroscope alarm system yields good prediction of laser intensity levels under degraded conditions characterized by noisy data and abrupt intensity changes.

Johnston closes the special section with an evolutionary algorithm solution to a multi-objective scheduling problem for NASA Deep Space Network communications. The evolutionary multi-objective optimization approach solves example ground network antenna scheduling problems involving severe resource contention and conflict resolution. The initial results hold strong potential to facilitate future space communications scenarios involving many concurrent space missions that each demand improved qualities of service from Earth networks within a new infrastructure of many more antennae than exist in the current Deep Space Network architecture.

The collection of articles herein reveals the richness of ongoing research and development focused on exploiting the benefits of soft computing for space systems autonomy. Results of the techniques and applications represented herein will contribute to continued progress toward understanding and solving essential problems associated with achieving the high levels of autonomy that will enable future space missions.

The Guest Editors would like to sincerely thank the authors for their valuable contributions to this special section. We are also grateful to the Editor-in-Chief Professor Mo Jamshidi for supporting the overall effort of bringing these technical contributions to readers of the journal.

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