Guest Editorial
Introduction to the Focused Section on Mechatronics in Multirobot Systems

I. INTRODUCTION

MULTIROBOT system technology has progressed rapidly from simulation, to laboratory prototyping, to realization of real-world applications. The vision of multirobot systems promises benefits such as: redundancy; fault tolerance; increased coverage and throughput; flexible reconfigurability; and spatially distributed sensing, actuation, and functionality. Applications capable of exploiting such features range from remote and *in situ* sensing to the physical manipulation of objects, and the domains for such applications include land, sea, air, and space.

While multirobot systems offer many advantages and increased potential with respect to single robots, there are still many challenges in their design, realization, and control that must be overcome in order to field cost-effective and efficient multirobot systems. To name a few of these challenges, we consider the following: inter- and intracommunications among the multirobot systems, relative position sensing, real-time multirobot system controls, fusion of distributed sensors/actuators, efficient man–machine interfaces for supervision and interaction, and design approaches supporting the economical production of such systems.

This Focused Section on Mechatronics in Multirobot Systems of the IEEE/ASME TRANSACTIONS ON MECHATRONICS is dedicated to new advances in mechatronics that are applicable to multirobot systems. In this editorial, we will highlight some articles related to this topic published in previous issues of the IEEE/ASME TRANSACTIONS ON MECHATRONICS, then highlight the articles published in this Focused Section, then describe some of the potential research trends in the related areas.

II. HIGHLIGHTS OF RELATED ARTICLES PUBLISHED IN THE IEEE/ASME TRANSACTIONS ON MECHATRONICS

A. 1998

Kubitz *et al.* have presented important features of a client–server approach to a mobile robot application to achieve the abstraction between hardware and software layers [1]. The servers decouple hardware and software dependencies. Communication is realized through the use of classes, offering a wide variety of client–server interaction. Event-driven servers and clients lead to quick responses in dynamic environments. The approach presented in the paper gives reusability, portability, testability, and maintainability through data abstraction.

Alleyne *et al.* have investigated the use of photo resistive light sensor arrays as a possible lateral position sensing system for a vehicle, or several vehicles, following a lead vehicle under separate control [4]. The authors have shown that the proposed sensing array has several benefits, including cost, simplicity, redundancy, and near linearity. Experimental results are given for a scaled vehicle following maneuver using a simple lateral control strategy. The results show that the sensor array may be attractive for lateral alignment in vehicle-following maneuvers.

B. 2000

Luo and Chen have developed a multiagent control taxonomy for a networked mobile robot in order to avoid disturbances injected by communication latency in such systems [7]. They adopt a behavior-programming control concept in which primitive onboard intelligence is grouped into a motion planner, a motion executor, and a motion assistant. These are integrated into a centralized control architecture, and an event-driven system is used to switch behaviors to accommodate unpredicted mission demands. This approach has been successfully demonstrated in comparative experiments with direct remote control techniques.

C. 2001

Zergeroglu *et al.* have used visual servoing techniques to control a planar robot in the presence of uncertainties [8]. By using mechanical parameters, they were able to adapt the control to compensate for these uncertainties in order to achieve global position tracking. In this paper, both the theoretical and experimental results are presented. While this is only for a single robot, the topic could be extended to cover multiple robots.

D. 2002

Sun and Mills have developed an approach to nonmodel-based decentralized controls of multirobot systems, utilizing structural flexibility in gripper design to avoid large unwanted internal forces acting on multirobot systems [11]. The authors prove that a simple proportional–derivative (PD) position feedback plus gravity compensation controller can regulate the desired position/orientation of a payload manipulated by multiple robots with compliant grippers and simultaneously damp vibrations of compliant grippers. The addition of a force feedforward to the PD control scheme allows to develop a hybrid position/force scheme to control internal forces between robots and the payload in suitable directions. Experiments conducted with two CRS A460 industrial robots manipulating a beam, using a rigid and a compliant gripper, are reported.

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Castano *et al.* have described a robotic module developed in the framework of the Conro Project; the project is aimed at building deployable modular robots that can reconfigure into different shapes such as snakes or hexapods [12]. Since each Conro module is itself a robot, a Conro robot is actually a multirobot system. The paper presents an overview of the Conro modules, the design approach, an overview of the mechanical and electrical systems, and a discussion on size versus power requirement of the module. Each module is self-contained; it has its own processor, power supply, communication system, sensors, and actuators. The modules, although self-contained, were designed to work in groups, as part of a large modular robot. The paper also describes some of the robots that we have built using the Conro modules.

Støy *et al.* have presented a role-based approach to the problem of controlling locomotion of chain-type self-reconfigurable robots [13]. Role-based control is used to implement a sidewinder and a caterpillar gait in the Conro self-reconfigurable robot (see [12]). The robot is made from up to nine modules connected in a chain; hence, it can be seen as a multirobot system. The authors show that the locomotion speed of the caterpillar gait is constant even with loss of 75% of the communication signals and that the speed of the caterpillar gait decreases gracefully with a decreased number of modules. The authors also implement a quadruped gait and show that without changing the controller, the robot can be extended with an extra pair of legs and produce a hexapod gait.

Butler *et al.* have developed a distributed self-reconfiguring robot system with unit-compressible modules called the Crystal robot [14]. A new design for the crystal module is presented that decouples the x-axis and y-axis actuation and has onboard sensing and neighbor-to-neighbor communication. The authors describe a suite of distributed control algorithms and related experiments for this type of robot; nevertheless, several of the algorithms presented are instantiations of generic distributed algorithms for self-reconfiguring robots. In detail, an algorithm for distributed goal recognition, two new distributed locomotion algorithms designed for unit-compressible actuation, and a new generic-division algorithm are presented. The integration of a locomotion algorithm with distributed goal recognition allows the robot to reconfigure and recognize the achievement of its goal without the use of a central controller.

Murata *et al.* have presented a novel robotic system called modular transformer (M-TRAN) [15]. M-TRAN is a distributed, self-reconfigurable system composed of homogeneous robotic modules. The system can change its configuration by changing each module's position and connection. Each module is equipped with an onboard microprocessor, actuators, intermodule communication/power transmission devices, and intermodule connection mechanisms. The special design of M-TRAN module realizes both reliable and quick self-reconfiguration and versatile robotic motion. An actual system with ten modules was built, and basic operations of self-reconfiguration and motion generation were examined through experiments. A series of software programs—including an user interface and a motion planner—has also been developed to drive M-TRAN hardware that are integrated into the M-TRAN system supervised by a host computer.

Yim *et al.* have described a three-phase docking process for chain modular robots [16]. These form systems with many degrees of freedom, which are capable of being reconfigured to form arbitrary chain-based topologies. This reconfiguration requires the detaching of modules from one point in the system and reattaching at another. The internal errors in the system (especially with large numbers of modules) are such that accurate movement of chain ends, required for the attaching of modules, can be extremely difficult. The docking process has been tested in experiments with a PolyBot prototype and the issues raised during this testing have been addressed in a later version of the prototype.

Brown *et al.* have aimed their work at enhancing the mobility of small mobile robots by enabling them to link into a train configuration capable of crossing relatively large obstacles [17]. The elementary module considered is the Millibot, a semiautonomous, tracked mobile sensing/communication platform at the 5 cm scale. The Millibot train concept provides couplers that allow the Millibot modules to engage/disengage under computer control and joint actuators that allow lifting of one module by another and control of the whole train shape in two dimensions. A manually configurable train prototype demonstrated the ability to climb standard stairs and vertical steps nearly half the train length. A fully functional module with powered joints has been developed and several have been built and tested.

Pryor *et al.* have developed an application of the generalized robotics software framework Operational Software Components for Advanced Robotics (OSCAR) for kinematic control of hyperredundant, self-reconfigurable systems [18]. OSCAR includes generalized kinematics, dynamics, device interfacing, and criteria-based decision making. The developed application allows an operator to interactively reconfigure modular chains into parallel mechanisms, gait structures, and multiarm systems while maintaining full kinematic control of each chain. Examples using spatial systems with various geometries are presented with application pseudocode to illustrate high-level program development.

E. 2003

Melek and Goldenberg have developed a practical intelligent-control architecture for the position control of modular and reconfigurable robots [19]. The architecture uses adaptive fuzzy gain tuning of proportional–integral–derivative parameters and provides learning control using feedforward neural networks. Furthermore, the architecture is capable of updating the adaptive control under reconfigurability. Together, these characteristics allow the controller to provide effective control in the face of unmodeled disturbances and with no *a priori* knowledge of system dynamics parameters. Experiments on a modular robot test bed are used to validate the control methodology's effectiveness.

Li and Yang have contributed to advances in a behavior-based subsumption architecture for fully autonomous mobile robots. In particular, they have developed a vision-based landmark recognition system that supports robot navigation [20].

This system uses a genetic algorithm-based search method for pattern recognition in order to identify artificial landmarks in comparison with predefined patterns. This control layer and its integration within the control architecture, which includes obstacle avoidance behaviors based on the use of eight ultrasonic sensors, are demonstrated through experimental studies.

Wang and Xu have explored stable full-state tracking for nonholonomic wheeled mobile robots under output tracking control laws [21]. They have shown how this formulation promotes better understanding of system dynamics and more insights to trajectory tracking stability. Sufficient conditions ensuring stable full-state trajectory tracking are derived. Using a mobile robot with a car-like configuration, they provide examples and simulation results confirming the presented theory, numerical analyses, and observations.

Donecker *et al.* have presented a new magnetic sensing system for intelligent transportation systems [22]. The system is applicable for vehicle control applications ranging from lane keeping during intelligent cruise control to driver assistance during highway maintenance functions. The newly developed magnetic system provides advantages in both hardware design and detection algorithms thereby providing improvements in performance, maintainability, and upgradability in comparison with existing systems.

F. 2004

Yuan and Yang have proposed a novel approach of automated multirobot nanoassembly planning and multirobots coordination [23]. The paper describes a new approach to improve self-organizing map to coordinate assembly tasks of nanorobots while generating optimized motion paths at run time with a modified shunting neural network and development of a possible system for real-time handling of environmental uncertainty.

Wu and Zhou have proposed the development of a colored resource-oriented Petri net (CROPN) modeling method to handle the conflict and deadlock arising in automated guided vehicles (AGV) systems by introducing and implementing the concept of colors in each node in the Petri net in order to avoid deadlock situations [24]. In any circuit (cyclic path) or deadlock situation, the node will fire the lane corresponding to the color that is activated by the AGV that arrives and asks for the resource (lane/node) first.

Sato *et al.* have come up with an environment-type robot system that features: 1) a spatial system; 2) a human–robot symbiosis system; and 3) a distributed system [26]. The authors have focused on behavior media, behavior contents, and behavior adaptation as the key research areas in the robotic room. The environment-type room system features three rooms that specialize in: 1) nonconstrained behavior measurement and recognition; 2) sensing and accumulating the behavioral database to identity daily-life regular behavior; and 3) distributed system prototyping with environmental and operational support to the human beings. The main contribution of the authors is toward behavioral adaptation through the use of human–robot symbiosis system.

Lee *et al.* have proposed an architecture for intelligent space based on distributed sensors that satisfies scalability, reconfigurability, modularity, easy maintenance, and affinity problems [27]. The paper introduces a Distributed Intelligent Networked Device (DIND) composed of sensor (charge-coupled device (CCD) camera), processor (Celeron 2.7 GHz PC), and communication parts (100 base TLAN card). A DIND monitors dynamic environment and is able to communicate with other DIND. Position data from sensor are processed in the localization engine and position information of possible targets is generated. DIND are modular and functions could be added in them to make them more useful. The deployment of DIND is minimally invasive to the environment and DINDs can communicate with relatively low intelligence robots in the environment and act as the sensing resource to the robots.

Lo *et al.* have presented a system that enables multiple operators at different sites to cooperatively control multiple robots [28]. The system is event based, and the delay in the control loop of one robot does not affect the other robot. The robots are distributed in the sense that there is no central controller. The main contribution of the paper is the separation of control loops. The only component that is common to both the loops is the interaction module that stores and outputs the most updated interaction force. This is human-in-the-loop system. However, the actual control input to the robot is calculated based on the human input, repulsive force from the environment, and the repulsive force from other robots.

G. 2005

Kamimura *et al.* have presented a design method and experiments for whole-body locomotion by a modular robot [30]. This study proposes a unified framework for automatically designing an efficient locomotion controller suitable for any module configuration. The method utilizes neural oscillators [central pattern generators (CPGs)], each of which works as a distributed joint controller of each module, and a genetic algorithm to optimize the CPG network. The authors have verified the method by simulations and experiments, in which the modular robotic system named M-TRAN II (see [15]) performed stable and effective locomotion in various configurations.

Shen *et al.* have developed a system of mobile safety barrel robots [31]. The robotic safety barrels can self-deploy and self-retrieve removing workers from this dangerous task. The robots move independently so they can be deployed in parallel and can quickly reconfigure as the work zone changes. The system must be reliable and have a low per-robot cost. A robot that malfunctions could create a significant hazard. Also, multiple barrels are used and they are often struck by vehicles; therefore, a high replacement cost is not practical. A six-robot system, which consists of a lead robot and five low-cost barrel robots, is described. A distributed planning and control approach is presented that reduces the per-robot cost by centralizing the intelligence and sensing while keeping communication bandwidth low by distributing local control. Test results are presented including a statistical analysis of the performance of the local robot controllers and field tests of the full system.

H. 2006

Tang *et al.* have focused on groups of robots that cooperatively transport objects. They specifically consider multiple mobile manipulator modules that collectively grasp a payload such that the resulting system is a composite multi-DOF wheeled vehicle that may be treated as an in-parallel system with articulated serial-chain arms. By applying analytic techniques from the field of constrained mechanical systems, they present a systematic framework for using the known characteristics of the individual robots in order to formulate and evaluate system-level performance such as mobility and disturbance rejection [32]. They use a two-module composite system to demonstrate and experimentally validate the technique.

Huang *et al.* have investigated the control and localization of heterogeneous groups of mobile robots in the context of having many simple, inexpensive, sensor-limited, and computationally-limited robots follow a more highly capable leader robot [33]. In their work, the leader performs complex sensing and computational tasks and also directs the simple operations of the followers. They apply their robots to highway safety applications in which the robots automatically deploy and maneuver safety barrels that are used to control traffic in highway work zones. They present theoretical and statistical analyses as well as experimental results of a tracking-based localization methodology as well as simple methods for follow-the-leader control and for changing the configuration of followers.

I. 2007

Yang and Gu have described the problems about nonlinear formation keeping and mooring control of multiple autonomous underwater vehicles (AUVs) in chained form and showed some simulation results by using their proposed method to solve the two control problems mentioned [34]. Their contribution is the design of control method based on particular control laws, such as integrator backstepping, formation control, and Lyapunov's direct method to make the system effectiveness.

Hwang and Chang have proposed a mixed $H2/H\infty$ decentralized control for car-like mobile robot (CLMR) in an intelligent space to obtain a piecewise line trajectory tracking and obstacle avoidance and developed an experimental platform for evaluation [35]. Their contribution is the implementation of the mixed $H2/H\infty$ decentralized control in the intelligent space system, and the experimental data are useful for evaluating algorithms and sensors.

J. 2008

Jan *et al.* have described some optimal path planning algorithms for navigating mobile rectangular robot among obstacles and weighted regions [36]. The approach is based on a higher geometry maze routing algorithm. Starting from a top view of a workspace with obstacles, the so-called free workspace is first obtained by virtually expanding the obstacles in the image. After that, an eight-geomerty maze routing algorithm is applied to obtain an optimal collision-free path with linear time and space complexities. The proposed method not only can search an optimal path among various terrains but also finds an optimal path for the 2-D piano mover's problem with 3 DOF. Furthermore, the algorithm can be easily extended to the dynamic collision avoidance problem among multiple autonomous robots or path planning in the 3-D space.

Caccavale *et al.* have studied the problem of impedance control of dual-arm cooperative manipulators [37]. A general impedance control scheme is adopted, which encompasses a centralized impedance control strategy, aimed at conferring a compliant behavior at the object level, and a decentralized impedance control, enforced at the end-effector level, aimed at avoiding large internal loading of the object. The overall control scheme is based on a two-loop arrangement, where a simple PID inner motion loop is adopted for each manipulator, while an outer loop, using force and moment measurements at the robots wrists, is aimed at imposing the desired impedance behaviors. The developed control scheme is experimentally tested on a dual-arm setup composed of two 6-DOF industrial manipulators carrying a common object.

III. HIGHLIGHTS OF THIS FOCUSED SECTION

This Focused Section includes the following.

Yang *et al.* investigate accurate posture estimation and coordinate control of a twin hoisting-girder transporter cooperating to manipulate and transport a large-scale object in their paper, "Posture Measurement and Coordinated Control of Twin Hoisting-Girder Transporters Based on Hybrid Network and RTK-GPS." An integrated framework for communication and control is developed based on a hybrid network. The relative distance and orientation between the two transporters while traveling is obtained by data fusion: the Real-Time Kinematic Global Positioning System (RTK-GPS) is used for locating the transporter while in-vehicle speed sensors give speed measurement. This method allows a high-update rate posture and speed estimation. Based on the hybrid networked control system, a distributed master–slave coordinated control strategy is proposed to ensure that the cooperation tasks (i.e., lifting/lowering and transporting girder) are achieved reliably and flexibly. The experimental and practical application results show that relative distance deviation between the master Hoisting-girder Transporter and the slave one is not more than 0.1 m, and relative orientation angle deviation is not more than 0.2°, which means the localization method and coordinated control strategy can meet the accuracy and robustness requirements of the synchronization control.

Pugh *et al.* present an onboard robotic module, which can determine relative positions among miniature robots in their paper, "A Fast Onboard Relative Positioning Module for Multirobot Systems." The module uses high-frequency modulated infrared emissions to enable nearby robots to determine the range, bearing, and message of the sender with a rapid update rate. A Carrier Sense Multiple Access (CSMA) protocol is employed for scalable operation. A technique for calculating the range and bearing between robots is developed, which can be generalized for use with more sophisticated relative positioning systems. Using this method, the accuracy of positioning between robots is characterized and different sources of imprecision are identified. Finally, the utility of this module is clearly demonstrated with several robotic formation experiments, where precise multirobot formations are maintained throughout difficult maneuvers.

Franchi *et al.* develop a decentralized cooperative exploration strategy for a team of mobile robots equipped with range finders. A roadmap of the explored area, with the associate safe region, is built in the form of a sensor-based random graph (SRG) in their paper, "The Sensor-Based Random Graph Method for Cooperative Robot Exploration." This is expanded by the robots by using a randomized local planner that automatically realizes a tradeoff between information gain and navigation cost. The nodes of the SRG represent view configurations that have been visited by at least one robot and are connected by arcs that represent safe paths. These paths have been actually traveled by the robots or added to the SRG to improve its connectivity. Decentralized cooperation and coordination mechanisms are used so as to guarantee exploration efficiency and avoid conflicts. Simulations and experiments are presented to show the performance of the proposed technique.

Viguria and Howard investigate the multirobot task formations problem and focus on the comparison between two algorithms to optimize the system in their paper, "An Integrated Approach for Achieving Multirobot Task Formations." One algorithm is basic market-based algorithm (BS) and the other is robot and task mean allocation algorithm (RTMA), which is modified based on the BS. The authors have shown simulation results, error, and data analysis. They have also demonstrated their result on the iRobot Create platform.

Takahashi *et al.* have compared the phase-diffusion time-division (PDTD) method, a communication timing control method based on phase dynamics for collision avoidance in a mesh sensor network, with CSMA in their paper, "Communication Timing Control and Topology Reconfiguration of a Sink-Free Meshed Sensor Network With Mobile Robots." The PDTD method is self-tuning and can operate without global information. The authors have experimentally shown an increased performance in terms of network throughput when using the proposed method as compared to CSMA. The PDTD method is further exploited and tested in situations where the network topology is dynamic. A mobile sink node is used and the network is reconfigured at regular intervals. Results have shown that though the throughput declines when the sink node is on the move, it reaches the previous high levels once the sink node arrives at the next target location. It was shown that PDTD works in both dynamic and unknown network topologies. However, the downside of PDTD is that it does not perform well in terms of network delay. There are delays as much as 3 s per node.

Sariel-Talay *et al.* deal with the multiple traveling robot problem (MTRP) in their paper, "Multiple Traveling Robot Problem: A Solution Based on Dynamic Task Selection and Robust Execution." They mention the significance of solving MTRP problem in many different constrained scenarios and also in case of many different real-world applications. The authors propose a globally efficient framework that carries incremental task allocation method dynamically adapting to the current environmental conditions. They also mention the current optimization methods and tools available in literature, and they discuss the advantages and disadvantages of these methods for different applications. They do demonstrate their algorithm and solution to MTRP on a multirobot platform and compare it with other methods. This is a well-written paper and deals with a very important research topic.

Kitts and Mas propose a conceptual framework for multirobot motion specification and formation control in their paper, "Cluster Space Specification and Control of Mobile Multirobot Systems." In this approach, a group of robots is defined as a cluster, with attributes such as position, orientation, and geometry. These attributes guide the selection of a set of independent state variables, which define the cluster space and which are used to simplify the specification and monitoring of aggregate robot motion. Kinematic transforms are introduced to convert cluster space motion specifications into robot space vehicle commands and from robot space vehicle motions back to cluster space motion behaviors. The authors verify the approach with experiments on planar two- and three-robot clusters, and they discuss implementation issues regarding singularities, computational complexity, and state variable selection.

Khoo *et al.* present a new method for multiple mobile robots to track a leading robot in their paper, "Robust Finite-Time Consensus Tracking Algorithm for Multirobot Systems." The method utilizes a terminal sliding mode control surface to achieve finite-time consensus tracking. The tracking robots will reach a consensus on the position and tracking of the leading robot. The tracking robots can also be set to reach a set deviation from the leading robot in order to hold a formation that follows the leading robot. The main contribution of the paper is that the tracking robots reach consensus in finite time rather than asymptotically approaching consensus. The authors demonstrate how the algorithm could be implemented using AmigoBots but there are very few details on any implementation of the proposed algorithm.

Wang *et al.* address the representation and reconfiguration of the group configurations assembled by wheel-manipulator robots in their paper, "Reconfiguration of a Group of Wheel-Manipulator Robots Based on MSV and CSM." The wheel-manipulator robot as a module, which can independently perform the actions of locomotion and manipulation, possesses the properties of the postural orientation and the locomotive direction. The module state vector (MSV) is proposed to represent the state of the asymmetric robotic module while the configuration state matrix (CSM) is introduced to represent the group configuration of these robots. The algorithms are proposed for assembling optimally the configuration of individual modules and transforming optimally the configurations of the robots. Their validity is evaluated and demonstrated through numerical simulations.

Parker and Zhang describe a biologically inspired algorithm that enables a decentralized multiple robot systems (MRS) composed of very simple robots to make good, unanimous decisions in their paper "Cooperative Decision Making in Decentralized Multiple-Robot Systems: The Best-of-*N* Problem." In a series of physical experiments using real robots, the best decision was made at least 80% of the time. One-hundred percent of the decisions achieved perfect consensus, which prevented the MRS from becoming fragmented. The decisions are made using only anonymous, local communication, with no direct comparisons of the available alternatives by the individual robots.

IV. FUTURE TRENDS

With increasing popularity and interest in multirobot systems, there are many research topics with huge potential to make these mechatronics systems possible in real-life applications. Here is some thought about emerging research trends in mechatronics in multirobot systems.

As the number of industry and public domain applications increase, the real-time secured control is an important issue. This gives rise to a real-time optimization problem and security threat-modeling requirement in network-based mechatronics. With multicomponents, designing a fault tolerant control (FTC) system for large-scale complex mechatronic systems is still very difficult due to the large number of sensors and actuators spatially distributed. With the help of technologies like GPS, electronics atlas (Google maps), we are looking at multiagent traffic control in urban areas with efficient vehicle communication. However, the problem is not restricted to just vehicular communication, but it also includes correct data estimation, data fusion in real time to make robust decisions with all the mechatronic components (here vehicles can be treated as robots) of traffic management that has a huge research potential. Scheduling different processes and bandwidth allocation for multirobots in mechatronic systems is looked upon from communication and network perspective so far. Solving the problem from control perspective is still challenging in real-time systems where each robot has a deadline for the task assigned to it. Designing control parameters as a function of bandwidth available, allocated, and also other robots in the system is a very important problem for researchers and engineers.

Another issue worthy of future investigation concerns methods for building shared collective knowledge. This topic already includes methods for cooperative localization and mapping but might be generalized to develop, for example, collective decision-making approaches.

An interesting feature to implement in future multirobot systems is plug-and-play reconfiguration. This will allow one to freely add or remove team members, even of different types, as needed by the mission under execution.

Real-life applications finally call for the implementation of high-level capabilities to efficiently handle in autonomy unplanned scenarios in unstructured environments. This motivates the development of artificial cognitive systems to achieve the situation awareness needed for proper action planning and control. A further challenge is to enable new human–robot interfaces that allow a single operator to efficiently specify the action of the multirobot system and understand the real-time operation of the system. This will require innovations in autonomously deriving task plans and low-level commands from high-level abstract goals, in providing abstracted summarizations of system state, and in implementing advanced multimodel human–machine interfaces that potentially draw upon new research in haptics and spoken dialogue systems.

Due to the vast amount of work on mechatronics in multirobot systems and the limited number of pages, the Guest Editors, apologize for not being able to list all the related work in this editorial. We hope that this Focused Section can serve as one of the catalysts to further propel the important mechatronics in multirobot systems technologies forward.

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