Guest Editorial: Advanced Motion Control for Mechatronic Applications With Precision and Force Requirements

MOTION control (MC) is concerned with all the issues arising in the control of the movement of a physical device. This means that MC is not limited to the use of proper devices for sensing and actuation, in addition to suitable control algorithms, but it also deals with all the possible interactions of the controlled devices with the environment. This is the most remarkable aspect of MC, nowadays deployed in numerous mechatronic systems, especially those which are dynamically acting in heterogenous, time-varying, active, and human-accessible environments. With the progress of new technological solutions and design methods in the MC systems, like virtual sensors, human-machine and environmental interfaces and, above all, novel control strategies including observation, adaption, and precision and robustness enhancing techniques, the level of MC performance further raised in the last years. Especially, the mechatronic systems which have comprehensive application-specific requirements on the precision of controlled motion and the complying interactive forces are benefiting from the advanced MC techniques and related methods. Reduced energy consumption when inducing a controlled motion appears as an additional challenge.

In order to describe what is MC nowadays, it is necessary not only to talk of the traditional issues (which indeed had quite a progress during the last decade), but also to introduce some innovative problems addressed by MC, like the control of high-precision positioning systems, robust, and adaptive MC applications, haptic and force control in robotics and mechatronics, as well as hybrid and discrete MC systems.

Given the above considerations, the special section on "Advanced MC for Mechatronic Applications with Precision and Force Requirements" has been promoted by the Technical Committee on MC of the IEEE Industrial Electronics Society, aiming at bringing to the large IEEE Industrial Electronics Society audience the most advanced and relevant results in the field of MC.

The interest of this subject for our research community has been proven by about 70 manuscripts submitted, out of which 17 were finally accepted, after a rigorous peer reviewing process. The manuscripts presented in this special section include a group of three on new actuators, while the remaining ones are dealing with various aspects of control in MC, namely disturbance compensation, high precision control, predictive control, interaction force control, robust and adaptive control.

The novel actuators described in this special section include a small two-dimensional robotic spherical joint using a bonded-type piezoelectric actuator, capable to achieve the high-resolution rotary motions around two orthogonal axes [item 1) in the Appendix], a compact cantilever ultrasonic motor with nanometer resolution [item 2) in the Appendix] and a new high-precision self-bearing linear actuator [item 3) in the Appendix].

New disturbance compensation studies are presented in two different papers, with applications to an adaptive nonsingular terminal sliding mode controller in a magnetic levitation system [item 4) in the Appendix] and in a current-constrained controller for the speed regulation in a permanent magnet synchronous motor (PMSM) with unmatched disturbances [item 5) in the Appendix].

Relevant cases of high precision control are discussed in four contributions, including a nontrivial case of application of dual-stage control solutions to a pointing mechanism used in miniature satellite laser communication terminals [item 6) in the Appendix], a study for enlarging the available control bandwidth and accuracy in an atomic force microscope [item 7) in the Appendix], a predictive high accuracy position control for long stroke planar motors [item 8) in the Appendix], and a data-based learning adaptive robust control strategy based on gated recurrent unit neural network control for the implementation of an accurate tracking error prediction [item 9) in the Appendix].

Predictive control is the main topic of two papers of this special section. The first proposes a predictive position control method of planar motors using trajectory gradient soft constraint with attenuation coefficients in the weighting matrix to achieve high-precision, time-varying, and long-stroke positioning [item 10) in the Appendix]. The other presents a novel model predictive control for a three-phase PMSM with enhanced robustness against parameter variation and higher current control precision [item 11) in the Appendix].

The control of the interaction force of MC system is becoming a hot topic, as the human-device interaction is becoming popular, even in an industrial setting. This special section accounts four contributions in this area and it includes a study on a high-robustness force control against the variation of the environmental stiffness [item 12) in the Appendix], an external

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force estimation estimator for linear series elastic actuators that does not need the usual load-side encoder [item 13) in the Appendix], a new controller to enhance the passivity of series elastic actuator which can accommodate the load-side damping under appropriate realtime monitoring of system's energy [item 14) in the Appendix], and an identification and compensation methodology for nonlinear internal disturbances in a voice coil motor (VCM) to accomplish precise force control with a linear VCM stage [item 15) in the Appendix].

Finally, robust performance is addressed by the last two manuscripts, reporting a robust control system of a virtual reality spherical motion platform capable of controlling six degree-of-freedom motion with unlimited rotational motion [item 16) in the Appendix] and the use of wavelet neural network to estimate unknown system dynamics in a networked multirobot system, while providing synchronization in collaborative tasks [item 17) in the Appendix]

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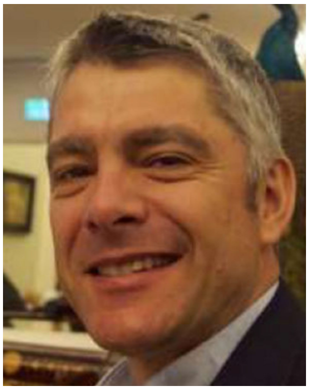
Appendix
Related Works

1) X. Gao, S. Zhang, J. Deng, and Y. Liu, "Development of a small two-dimensional robotic spherical joint using a bonded-type piezoelectric actuator," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 724–733, Jan. 2021.
2) L. Wang, Y. Guan, Y. Liu, J. Deng, and J. Liu, "A compact cantilever type ultrasonic motor with nanometer resolution: Design and performance evaluation," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 734–743, Jan. 2021.
3) S. Miric, R. Giuffrida, D. Bortis, and J. Kolar, "Dynamic electromechanical model and position controller design of a new high-precision self-bearing linear actuator," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 744–755, Jan. 2021.
4) J. Wang, L. Zhao, and L. Yu, "Adaptive terminal sliding mode control for magnetic levitation systems with enhanced disturbance compensation," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 756–766, Jan. 2021.
5) C. Dai, T. Guo, J. Yang, and S. Li, "A disturbance observer-based current-constrained controller for speed regulation of PMSM systems subject to unmatched disturbances," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 767–775, Jan. 2021.
6) R. Antonello, F. Branz, F. Sansone, A. Cenedese, and A. Francesconi, "High-precision dual-stage pointing mechanism for miniature satellite laser communication terminals," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 776–785, Jan. 2021.
7) S. Ito, M. Poik, J. Schlarp, and G. Schitter, "Atomic force microscopy breaking through the vertical range-bandwidth tradeoff," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 786–795, Jan. 2021.
8) S.-D. Huang, G.-Z. Cao, J. Xu, Y. Cui, C. Wu, and J. He, "Predictive position control of long-stroke planar motors for high-precision positioning applications," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 796–811, Jan. 2021.
9) C. Hu, T. Ou, Y. Zhu, and L. Zhu, "GRU-type LARC strategy for precision motion control with accurate tracking error prediction," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 812–820, Jan. 2021.
10) S.-D. Huang, L. Chen, G.-Z. Cao, C. Wu, J. Xu, and Z. He, "Predictive position control of planar motors using trajectory gradient soft constraint with attenuation coefficients in the weighting matrix," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 821–837, Jan. 2021.
11) S. Niu, Y. Luo, W. Fu, and X. Zhang, "Robust model predictive control for a three-phase PMSM motor with improved control precision," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 838–849, Jan. 2021.
12) Y. Kawai, Y. Yokokura, K. Ohishi, and T. Miyazaki, "High-robust force control for environmental stiffness variation based on duality of two-inertia system," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 850–860, Jan. 2021.
13) M. Yokoyama, R. A. B. Petrea, R. Oboe, and T. Shimono, "External force estimation in linear series elastic actuator without load-side encoder," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 861–870, Jan. 2021.
14) H. Lee, J. Ryu, J. Lee, and S. Oh, "Passivity controller based on load-side damping assignment for high stiffness controlled series elastic actuators," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 871–881, Jan. 2021.
15) K. Ohno, K. Ito, T. Yamada, J. Sato, Y. Shiroyama, and T. Hamajima, "Disturbance suppression considering thrust constant fluctuation and restoring force of flat cable for precise force control," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 882–891, Jan. 2021.
16) S.-M. Lee, K. Xia, and H. Son, "Robust tracking control of spherical motion platform for virtual reality," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 892–901, Jan. 2021.
17) V.-T. Ngo and T.-C. Liu, "Object transportation with force-sensorless control and event-triggered synchronization for networked uncertain manipulators," *IEEE Trans. Ind. Electron.*, vol. 68, no. 1, pp. 902–912, Jan. 2021.



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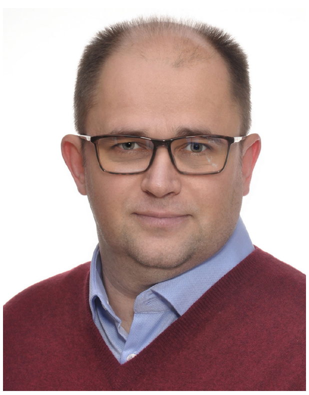

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