

Sliding Mode Control and Observation for Complex Industrial Systems—Part I

WITH the recent rapid developments in industrial technology, the modern industrial systems have become more and more complex requiring a greater attention to be paid on the stabilizability, the robustness, the reliability, and the optimization issues. The recent developments in sliding mode control and observation techniques serve as powerful tools in this respect. The use of sliding mode control offers a number of advantages: insensitivity to external disturbances, system reduction, high accuracy, and finite time convergence. However, there are still several remaining issues that should be solved before it can be extensively used in the industry in the near future, that is, chattering effect, requirement of an accurate model of the system, relative higher complexity and higher implementation cost compared to existing linear controllers. This “Special Section on Sliding Mode Control and Observation for Complex Industrial Systems—Part I” of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS presents to the industrial electronics community the most recent advances with topics, such as applications of sliding mode control in industrial electronics (power grid, uninterruptible power supply, robot manipulators, etc.), design and implementation issues of sliding mode control and observation techniques.

It is our pleasure to present this Special Section. Due to the high number of good papers submitted, this Special Section will be divided into two parts.

In item 1) of the Appendix, a hybrid active–passive linear heave compensation system with a nonlinear cascade controller is designed to reduce the adverse effect of the unexpected vessel heave variation on the response of the underwater payloads. An adaptive extended disturbance observer is constructed to estimate and separately compensate the external perturbations. Sliding mode control is designed for the outer position tracking loop in order to compensate the disturbance estimation error while the backstepping technique is employed in the inner pressure control loop.

In item 2) of the Appendix, a novel state/model-free variable-gain discrete sliding mode control strategy is presented to suppress the unmolded position-dependent dynamics and disturbances in the nanopositioning wafer stage. To balance the tradeoff between the robustness and the chattering, the gain of the switching control term is designed to be variable. The proposed scheme facilitates a rapid implementation without either a parameter model or a state observer, and excellent tracking performance with the optimal controller parameters.

In item 3) of the Appendix, a modeling approach of complex microgrids and its sliding mode control design is presented in a decentralized way. Second-order sliding mode control scheme based on suboptimal algorithm is designed for DGUs, taking unknown load dynamics, nonlinearities, and unavoidable modeling uncertainties into account.

In item 4) of the Appendix, a novel sliding mode control approach is proposed for a class of nonlinear systems, where a nonlinear sliding surface is designed using implicit function theory. Then, the proposed method is applied to solve the tracking control problem of a two-wheeled mobile robot, which can be transferred to a stabilization problem for the corresponding tracking error system.

A kernel independence criterion based on independent component analysis algorithm for fault monitoring is proposed in item 5) of the Appendix. Given kernel independence criterion in Regeneration Hilbert space, an exact objective function is given. The proposed approach is compared with the conventional kernel-independent component analysis in view of calculation accuracy and computational efficiency.

A new event-triggered sliding mode control algorithm is proposed in item 6) of the Appendix to solve the load frequency control problem of multiarea interconnected power systems. The prescribed H_∞ , or energy-to-energy, performance is utilized to test the effectiveness of the corresponding disturbance attenuation. Sufficient conditions for the stability analysis of the considered system are derived. Load frequency control problem is also addressed in item 7) of the Appendix, due to the fact that it causes frequency oscillations among interconnected power systems. An adaptive supplementary control method based on sliding mode technique and adaptive dynamic programming strategy is proposed for the power system frequency regulation taking disturbances and parameter uncertainties into account.

In item 8) of the Appendix, direct yaw-moment control strategies are proposed for in-wheel electric vehicles by using sliding mode and nonlinear disturbance observer techniques. A second-order sliding mode controller is designed by taking the derivative of the controller as a new control to tackle the chattering problem. The derived sliding mode control and a nonlinear disturbance observer are combined as a composite control to avoid the large control gains. The proposed method is compared with a traditional discontinuous first-order sliding mode controller.

A dc voltage incipient sensor fault isolation method is proposed in item 9) of the Appendix for single-phase three-level rectifier devices in high-speed railway electrical traction systems. By combination of sliding mode technique with nonlinear parametrization adaptive estimation technique, a new

incipient fault isolation method is developed for the considered systems. The isolable sufficient conditions are derived using new functions.

In item 10) of the Appendix, a robust finite-time anti-sway tracking control method is developed for three-dimensional overhead crane systems using sliding mode technique. The proposed sliding mode based robust finite-time anti-sway tracking control method is designed by considering variation in payload weight, the initial sway angles, and parameter uncertainties due to the payload weight uncertainty.

An integral sliding mode controller is developed for a general type of underwater robots in item 11) of the Appendix. An adaptive multi-input and multioutput extended state observer is designed to estimate the unmeasurable linear and angular velocities and the unknown external disturbances. An adaptive gain update algorithm is introduced to estimate the upper bound of the uncertainties. Finally, the proposed control method is applied to solve the tracking problem of the underwater robot.

In item 12) of the Appendix, an adaptive integral sliding mode control method with time-delay estimation is proposed. Parameter variations and disturbances are estimated via time-delay estimation approach. Integral sliding surface is designed to eliminate the reaching phase and an adaptive gain dynamics is employed to high tracking accuracy.

In item 13) of the Appendix, a high-performance sliding mode control is proposed to control the output voltage of the four-leg inverter with fixed switching frequency for uninterruptible power supply applications. The proposed control achieves chattering reduction, robustness, regulation, and dynamic response of the considered system. Practical implementation of the proposed method on a real test bench is also discussed.

For the three-dimensional gliding motion of a dolphin-like gliding robot, the work in item 14) of the Appendix presents a sliding mode observer-based heading control scheme. To regulate the gliding direction, a pair of flippers are used via differential actions, rather than actuators commonly used in traditional underwater gliders. Based on a dynamic model, including a sliding mode observer, a backstepping controller, and a solver for action commands of the flippers, a framework of the control algorithm is established.

To this end, the overview of all 14 papers of the Special Section—Part I has been completed. The Guest Editors hope that this Special Section will increase the interest of both the scientific and industrial communities in this very dynamic area and will attract more attention to producing new ideas and algorithms for future research applications.

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APPENDIX RELATED WORK

- 1) S. Li, J. Wei, K. Guo, and W.-L. Zhu, "Nonlinear robust prediction control of hybrid active-passive heave compensator with extended disturbance observer," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6684–6694, Aug. 2017.
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- 3) M. Cucuzzella, G. P. Incremona, and A. Ferrara, "Decentralized sliding mode control of islanded AC microgrids with arbitrary topology," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6706–6713, Aug. 2017.
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- 6) X. Su, X. Liu, and Y.-D. Song, "Event-triggered sliding-mode control for multi-area power systems," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6732–6741, Aug. 2017.
- 7) C. Mu, Y. Tang, and H. He, "Improved sliding mode design for load frequency control of power system integrated an adaptive learning strategy," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6742–6751, Aug. 2017.
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- 10) D. Chwa, "Sliding-mode-control-based robust finite-time antisway tracking control of 3-D overhead cranes," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6775–6784, Aug. 2017.
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- 13) M. Pichan and H. Rastegar, "Sliding-mode control of four-leg inverter with fixed switching frequency for uninterruptible power supply applications," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6805–6814, Aug. 2017.
- 14) J. Yuan, Z. Wu, J. Yu, and M. Tan, "Sliding mode observer-based heading control for a gliding robotic dolphin," *IEEE Trans. Ind. Electron.*, vol. 64, no. 8, pp. 6815–6824, Aug. 2017.



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