Introduction to the Special Section on New Emerging Technologies in Motion Control Systems—Part I

TODAY, motion control technologies are introduced in a huge number of products: electric vehicles, robots, mass storage areas, machine tools, etc. Many new products have developed based on previous studies on motion control. Recent achievements in motion control have indicated that innovation in this area is accelerating. For example, many companies have put robots with force sensing to practical use in the past few years. They have a wide variety of applications such as deburring, polishing, and assembling. Further development of haptics is strongly required for telesurgery, rehabilitation, and nursing care support. The development of high-accuracy positioning/tracking control has shortened the access time of mass storage areas. Sophisticated integration of actuators and sensors technologies has created many innovative techniques for new motion control systems. It is quite obvious that motion control is becoming more and more important as one of the key technologies in industrial electronics.

Therefore, this "Special Section on New Emerging Technologies in Motion Control Systems—Part I" aims at presenting to the industrial electronics audiences the most advanced and relevant results in the field of motion control. The first part of the Special Section presents 14 papers from various areas.

The recent development on the studies in force control and haptics is quite significant. The first paper by Oh *et al.* generalizes and analyzes the structure and characteristics of force-sensorless power-assist control. The generalized structure reveals how force-sensorless power-assist control can achieve the assistance, and the transfer function analysis based on the structure addresses the robustness and assistance performance evaluation problems. The second paper by Phuong *et al.* proposes a force control system based on friction-free and noise-free force observation. A combination of a high-order disturbance observer and a Kalman filter is implemented in a field-programmable gate array with a high sampling rate. The force-sensing bandwidth is improved through the disturbance rejection by the high-order disturbance observer and the noise suppression by the Kalman filter. The third paper by Motoi *et al.* proposes a task realization method using a force-based variable compliance controller for flexible motion control systems. Several tasks, which include the position tracking and the contact with the environment, are actualized by using the proposed method. The fourth paper by Nozaki *et al.* extends the diagonalization method based on the modal disturbance observer and applied it to a multi-DOF system. It succeeded in suppressing the interference between the position and force control systems and realized a bilateral control system. The fifth paper by Mizoguchi *et al.* proposes a novel bilateral control design integrating a gyrator element in the design to improve tactile sense transmission under velocity scaling. The proposed method is effective in both scaling methods, namely, constant value scaling and scaling with derivation.

Control systems inspired by human or animal are also increasing in importance for further development of motion control. The sixth paper by Ueyama and Miyashita investigates the limb stiffness of a monkey during arm-reaching movements and suggests that the central nervous system may control the body according to a way similar to an optimal feedback law. The seventh paper by Yu and Iida proposes a design strategy of hopping robot based on elastic curved beams and actuated rotating masses and identifies the minimalist model that can characterize the basic principle of robot locomotion. The eighth paper by Shukor and Fujimoto presents the direct drive position control verification of a spiral motor, i.e., a newly developed high-thrust high backdrivable direct-drive three-phase permanent-magnet motor with a unique 3-D structure. The control performance of the direct drive of the spiral motor is verified in the experiment as a monoarticular actuator.

Control systems with learning schemes are also popular. The ninth paper by Zhang *et al.* proposes a graph-embedding-based learning method, in which the topology structures of graphs are designed to reflect the properties of the sample distributions. In applications to tracking, the graph-embedding-based learning is incorporated into a Bayesian inference framework cascaded with hierarchical motion estimation, which improves the accuracy and efficiency of the localization. The tenth paper by Huang *et al.* exploits two types of sampled-data current cycle iterative learning control schemes for high-performance tracking control of piezoelectric positioning stage systems. Low tracking error in the time domain and fast convergence speed in the iteration domain were concurrently achieved. The eleventh paper by Han and Lee presents a funnel dynamic surface control combined with fuzzy echo state networks for the prescribed tracking performance of a strict feedback multi-input multi-output nonlinear dynamic system. A new funnel variable is defined so that the funnel virtual control forces the tracking error to fall within funnel boundary, and an adaptive fuzzy echo state network method is also proposed to improve the approximation performance in conventional neural network algorithms.

In the area of high-performance control and sensing, several sophisticated control architectures and filters are developed. The twelfth paper by Maeda and Iwasaki proposes a circle condition-based feedback controller design. The method can systematically specify the disturbance suppression performance by giving arbitrary response poles and ensure the desired stability margin by the circle condition on a Nyquist diagram. The thirteenth paper, also by Maeda and Iwasaki, presents a mode switching feedback compensation based on rolling friction

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models for table drive systems. The compensation is applied to provide the desired settling performance with well suppression of both vibratory and slow responses. The fourteenth paper by Wang *et al.* proposes a method for vehicle body slip angle estimation using a nontraditional sensor configuration and a system model. A multirate Kalman filter with intersample compensation is designed because the control period of motors is much shorter than the sampling time of a normal camera.

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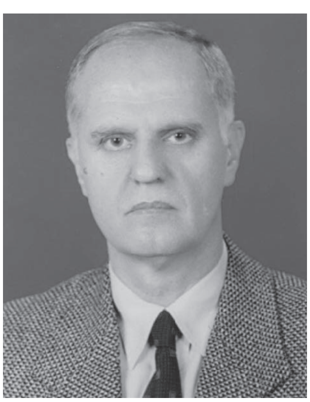

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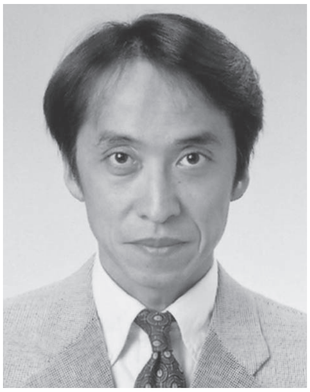

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