New Emerging Technologies in Motion Control Systems—Part II

TODAY, motion control technologies are introduced in a huge number of products, i.e., electric vehicles, robots, mass storage, machine tools, etc. Many new products have been developed based on previous studies on motion control. Recent achievements in motion control indicate 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. Development of high-accuracy positioning/tracking control has shortened the access time of mass storage. Sophisticated integration of actuator and sensor 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 II" aims to present to the industrial electronics audience the most advanced and relevant results in the field of motion control. It is our pleasure to present the second part of this special section since many cutting-edge studies have been contributed.

Recent developments of actuators and motor drives are first introduced as the fundamental part of motion control technology. The first paper by Fujimoto *et al.* deals with a spiral motor, i.e., a screw-shaped motor with high backdrivability. A power-saving axial-gap displacement adjustment method is proposed to solve the issue of copper loss due to the d-axis current [1]. The second paper by Aschemann and Schindele also deals with a linear actuator with high backdrivability, although the paper is on pneumatic muscles. Since hysteresis is the largest issue in using pneumatic muscles, the study compares the model-based approaches for the compensation of the hysteresis [2]. The third paper by Yao *et al.* deals with the control of dc motors. An adaptive control method with an extended state observer is proposed to account for an unstructured uncertainty [3].

Studies on mobile robots have been popular as an application of motion control technology. The fourth paper by Serón *et al.* proposes an autonomous climbing maneuver for tracked mobile manipulators. The method utilizes an onboard arm as an extra limb that can be pushed against the ground. The arm is also used for shifting the center of gravity of the robot [4]. The fifth paper by Suzumura and Fujimoto deals with a zero-moment-point-based whole-body motion generation and control systems for higher mobility of a wheel-legged mobile robot [5]. The sixth paper by Blažič proposes a unified framework for the control-law analysis and design of two types of wheeled mobile robots, i.e., those that are only capable of forward motion and those that can perform forward and backward motions [6]. The seventh paper by Xu *et al.* presents a novel implementation of a sliding mode controller on a two-wheeled mobile robot. An integral sliding mode controller is introduced for the regulation and set point control of an underactuated system with both matched and unmatched uncertainties [7]. The eighth paper by Sun *et al.* introduces an approach for the tracking control of a 7000-m manned submarine vehicle. A filter design using a bioinspired model is employed to handle the speed jump problem, which often causes a thruster saturation problem [8].

Studies on the motion control with higher accuracy have been also popular. The ninth paper by Fujimoto and Takemura presents a learning control method for a ball-screw-driven stage. A repetitive perfect tracking control with an n-times learning filter can converge the tracking error faster than the method with a conventional learning filter [9]. The tenth paper by Wu *et al.* presents a large measurement-range atomic force microscopy system with a z-scanner separated from a precision hybrid xy-scanner [10]. The eleventh paper by Zavari *et al.* extends an interpolation-based approach to design gain-scheduled controllers for linear parameter varying systems. Its validity was confirmed from the results on an overhead crane system with a varying cable length [11]. The twelfth paper by Horvat *et al.* presents an event-driven control of a mechatronic system. The developed supervisor system that is upgraded with a graphical user interface is for it to be safe, robust, effective, and user-friendly [12]. The thirteenth paper by Ruderman proposes a feedforward friction observer for the tracking control of a motor drive system with nonlinear friction. Introducing an explicit analytical form of the observation function, it has been shown that the full cancelation of friction disturbances can be guaranteed at steady-state conditions [13]. The fourteenth paper by Tian *et al.* considers the problem of the phase lags of a differentiator and proposes an idea to improve the differential estimate via feedforward [14]. The fifteenth paper by Yashiro and Yakoh proposes a traffic shaping algorithm for jitter buffers. Although the well-known dynamic jitter buffer needs to identify the maximum one-way delay and current one-way delay in the network, it is not necessary for the proposed approach to supply this information [15].

Recent studies in haptics are extending the ability of motion control systems in the real world. The sixteenth paper by Nakajima *et al.* proposes a bilateral control method for a surgical robot synchronizing with the heartbeat motion. Since the heartbeat motion is canceled with the method, the surgeon on the master side can feel the organ as if it is not moving [16]. The seventeenth paper by Yajima and Katsura extends the study of a motion-copying system to multiple degrees of freedom and analyzes the performance based on the velocity information. By using the proposal, it is possible to reproduce the saved motion, although the environmental location is shifted in a parallel manner [17]. The eighteenth paper by Lu *et al.* presents a development of a lower limb exoskeleton and a

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human-like learning controller for the neuromotor training of gait. The exoskeleton applies forces and learns the impedance parameters of both the robot and the human without a muscle model [18]. The last paper by Lee *et al.* presents a method of implementing impedance control on a dual-arm system by using the relative Jacobian technique. The method simplifies the control implementation by treating the dual-arm as a single manipulator [19].

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