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Editorial

Design and Control of Advanced Mechatronics Systems

Mingcong Deng [1,*], Hongnian Yu [2] and Changan Jiang [3]

[1] Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology, Tokyo 184-8588, Japan
[2] School of Engineering and the Built Environment, Edinburgh Napier University, Edinburgh EH11 4BN, UK; h.yu@napier.ac.uk
[3] Department of Robotics, Osaka Institute of Technology, Osaka 535-8585, Japan; changan.jiang@oit.ac.jp
* Correspondence: deng@cc.tuat.ac.jp; Tel.: +81-42-388-7134

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Research and experiments on mechatronics systems, which are a synergistic integration of mechanical engineering, electronic control, and systems concepts, have contributed significantly to the design of systems, devices, processes, and products. Effective systematic methods are still a challenging topic for the design and control of advanced mechatronics systems—especially for the potential of machine learning and optimal operation in engineering applications. This Special Issue provides an international forum for professionals, academics, and researchers to present the latest developments from theoretical studies, computational algorithm development, and applications of advanced mechatronic systems. The contents of these studies are briefly described as follows.

In the first work [1], through an H_∞ mixed sensitivity approach, a technique to design fixed structure controllers was presented for both continuous-time and discrete-time systems. Firstly, the feasible controller parameter set, which is the set of the controller parameters that guarantee robust stability of the closed-loop system and the achievement of the nominal performance requirements, was defined. Secondly, a convex relaxation of the original feasible controller parameter set was computed through Putinar positivstellensatz. Then, the original H_∞ controller design problem was formulated as the non-emptiness test of a set defined by sum-of-squares polynomials. Finally, the effectiveness of the proposed approach was shown by numerical simulations and experimental example.

The next work [2], aiming to improve the measurement accuracy, considered the temperature dependence of the thermal conductivity of a Peltier device, which is treated as a constant value. The control system considering the temperature dependence of the thermal conductivity was designed based on operator theory, which is a nonlinear control theory. The simulation and experimental results showed that the measurement accuracy was improved when the power loss was 10 W and 15 W compared to the case without considering the temperature dependence. In addition, the measurement time was reduced by about 100 s by considering the temperature dependence.

In the third work [3], an adaptive data-driven control approach was proposed for linear time-varying systems, affected by bounded measurement noise. The plant to be controlled is assumed to be unknown, and no information in regard to its time varying behavior was exploited. Firstly, using set-membership identification techniques, the controller design problem was formulated through a model-matching scheme. The problem was then reformulated as to derive a controller that corresponds to solve the formulated controller design problem by means of linear programming. The effectiveness of the proposed scheme is demonstrated by means of simulation examples.

The reinforcement learning control of an underground loader was investigated in a simulated environment by using a multi-agent deep neural network approach in [4]. At the start of each loading cycle, one agent selected the dig position from a depth camera image of a pile of fragmented rock. A second agent was responsible for continuous control of the vehicle, with the goal of filling the bucket at the selected loading point while avoiding collisions, becoming stuck, or losing ground traction. This relied on motion and force sensors, as well as on a camera and lidar. Using a soft actor–critic algorithm, the agents learned policies for efficient bucket filling over many subsequent loading cycles, with a clear ability to adapt to the changing environment. The best results—on average, 75% of the max capacity—were obtained when including a penalty for energy usage in the reward.

The study of [5] aimed to envisage and design the magnetic suspension system coupled with a single-winding bearingless motor and permanent magnet bearings, establish the theoretical models of axial force and electromagnetic torque, and calculate the stiffness of the magnetic suspension system at the equilibrium point. Addressing the problem of the negative axial stiffness of the magnetic suspension system being negative, which leads to the instability of the suspension rotor, the hydrodynamic bearing structure was proposed and designed, and the critical stiffness to realize the stable suspension of the rotor was obtained based on the stability criterion of the rotor dynamics model. The optimal structural parameters of the hydrodynamic bearing were selected by integrating various factors based on the solution of the Reynolds equation and a stiffness analysis. Experiment results proved that the blood pump rotor exhibited a good suspension stability.

The next paper [6] presented a performance-driven model predictive control algorithm for a two-dimensional underactuated bridge crane. In the proposed dual-layer control architecture, an inner-loop controller used a proportional–integral–derivative controller to achieve anti-sway rapidly. An outer-loop controller used MPC to ensure accurate trolley positioning under control constraints. Compared with classical MPC, this work proposed a data-driven method for plant modeling and controller parameter updating. By considering the control target at the learning stage, the method could avoid adjusting the controller to deal with uncertainty. The simulation and experimental results verified its effectiveness, feasibility, and superior performance on comparing it with state-of-the-art methods.

In the next work [7], the stiffness and optimization of driving force of the bio-inspired redundantly actuated chewing robot was studied. To understand the effect of the point-contact HKP acting on the RAPR performance, the stiffness of the RAPR was estimated based on the derived dimensionally homogeneous Jacobian matrix. In analyzing the influence of the HKP on robot dynamics, the driving forces of six prismatic joints were optimized by adopting the pseudo-inverse optimization method. Numerical results showed that the 6PUS-2HKP RAPR had better stiffness performance and more homogenous driving power than its non-redundant 6-PUS counterpart, verifying the benefits that the point-contact HKP brings to the RAPR. Experiments were carried out to measure the temporomandibular joint (TMJ) force and the occlusal force that the robot could generate. The relationship between these two forces in a typical chewing movement was studied.

The next four papers focused on the research on rehabilitation robots. In [8], a GANs-based (Generative Adversarial Networks) data augmentation method was created to generate synthetic human gait data while still retaining the dynamics of the real gait data. Then, both the real collected and the synthesized gait data were fed to our constructed two-stage attention model for gait trajectories prediction. Experimental results indicated that the created GANs-based data augmentation model could synthesize realistic-looking multi-dimensional human gait data. In addition, the two-stage attention model performs better compared with the LSTM model; the attention mechanism showed a higher capacity of learning dependencies between the historical gait data to accurately predict the current values of the hip joint angles and knee joint angles in the gait trajectory. The predicted gait trajectories depending on the historical gait data could be further used for gait trajectory tracking strategies.

In [9], the mechanism of the lower limb rehabilitation module was simplified and the geometric relationship of the human–machine linkage mechanism was deduced. Next, the trajectory planning and dynamic modeling of the human–machine linkage mechanism were carried out. Based on the analysis of the static moment safety protection of the human–machine linkage model, the motor driving force required in the rehabilitation process was calculated to achieve the purpose of rationalizing the rehabilitation movement of the patient's lower limb. To reconstruct the patient's motor functions, an active training control strategy based on the sandy soil model was proposed. Finally, the experimental platform of the proposed robot was constructed, and the preliminary physical experiment proved the feasibility of the lower limb rehabilitation component.

In [10], an end-effector finger rehabilitation robot (EFRR) with active A/A motion that can be applied to a variety of applications was proposed. Firstly, the natural movement curve of the finger was analyzed, which is the basis of the mechanism design. Based on the working principle of the cam mechanism, the flexion/extension (F/E) movement module was designed. and the details used to ensure the safety and reliability of the device were introduced. Then, a novel A/A movement module was proposed using components that can be easily individualized by design to achieve active A/A motion only by one single motor. As for the control system, a fuzzy proportional-derivative (PD) adaptive impedance control strategy based on the position information was proposed. Finally, some preliminary experiments of the prototype were reported, and the results showed that the EFRR had good performance.

In [11], an adaptive direct teaching function with variable load that can be applied to the sitting/lying lower limb rehabilitation robot-II (LLR-II) was proposed. Firstly, the structural design and electrical system of LLR-II were introduced. The dynamic equation of LLR-II considering joint flexibility was derived and analyzed. Then, the impact of joint flexibility on LLR-II was reduced by introducing the intermediate input variables. Based on this, the control law of the dragging teaching stage and the replay stage in the direct teaching function with variable load was designed, and the adaptive control strategy eliminates the influence of different patients. In addition, the control law was simulated and verified. Finally, some preliminary experiments of the adaptive direct teaching function with variable load on LLR-II were carried out, and the results showed that the control law had good performance.

As guest editors of this Special Issue, we would like to thank all the authors for their contributions. We wish that the readers can benefit from the above eleven papers. We would like to thank *Machines* for giving us the opportunity to serve as the guest editor for the Special Issue. Finally, we would like to thank the reviewers for their excellent job on evaluating these papers.

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