

EDITORIAL

From adaptive control to variable structure systems – seeking harmony

Special issue devoted to 70th birthday of Professor Liu Hsu

1. FOREWORD

‘Colleagues, coworkers, former students and friends of Professor Liu Hsu, from all over the world, join this special issue to celebrate his 70th birthday and recognize his extraordinary achievements during his long career as a researcher, educator and academic leader. Many of us have remained in touch with our dear friend Liu for decades, benefited from his support, admired his many talents and enjoyed his contagious *joie de vivre*. We have been inspired not only by his research vision and originality, but also by his humanity, broad culture and his love of music. In his quiet and modest manner he has been able to share his intellectual riches with all of us.

The remarkable academic career of Professor Liu Hsu will serve as a role model for many generations of researchers and educators in our field.’

Petar Kokotovic

‘Jubilee gives a good chance to express admiration for our good friend Professor Liu Hsu, a brilliant scientist and a charming personality. His research results in several areas of control theory and applications are well known to international control community. Professor Hsu has been a core figure in establishing international cooperation in sliding mode control, being a member of our IEEE Technical Committee and one of the organizers of our biennial international workshops within the last several decades. His own presentations and comments always caused interesting discussions. Not only scientific component attracts colleagues to participate in them, but his friendly manner of communications, tolerant reaction to doubtful arguments along with soft humor.

Dear Liu, it is your decision to retire, but keep in mind that we need you and hope, that joy of contacts with you will be with us for many years.’

Vadim Utkin

2. EDITORIAL

As highlighted in the recent special issues [1, 2], the field of adaptive control has grown and evolved over the past 50 years – its concepts, methods, and tools are by now well established cornerstones of many new fields and technical branches. A great deal of attention has been given to overcome the intrinsic limitations of classical adaptive control approaches. Thanks to the effort of many researchers, a novel class of strategies has appeared proposing new theoretical frameworks and reporting many successful technological applications.

Professor Liu Hsu is one of the important names in the field of adaptive control. He has made major contributions in this area proposing new control strategies of uncertain plants with guaranteed stability, robustness, and adaptability. Among his ground-breaking contributions, one finds the proof of existence of bursting phenomena in model reference adaptive controllers (MRAC) with leaky estimators, the so-called sigma modification. Then, he was able to develop a globally stable adaptive notch filter to determine online the frequency of a sine wave with unknown amplitude,

a particularly useful practical result in a wide variety of engineering applications. He and co-authors provided important contributions towards the solution of the longstanding problem of multivariable MRAC with unknown high-frequency gain matrix. In early works, an innovative combination of adaptive control and variable structure systems resulted in the pioneering variable structure (VS) MRAC. Later on, to improve the transient properties and robustness of sliding mode control, with the important advantage of having a continuous control signal free of chattering, he proposed the novel binary MRAC. These control strategies have been successfully applied to robot visual servoing and dynamic positioning of remotely operated underwater vehicles. In the last years, an open problem of global exact tracking was solved using a hybrid control version of the VS-MRAC and higher order sliding modes for chattering suppression. In addition, novel adaptive extremum-seeking controllers and nonlinear high-gain control strategies free of peaking were also proposed by him. In his most recent work, generalized passivity is being investigated to obtain fast adaptation and to reduce the complexity of adaptive controllers, opening a new avenue of research.

Professor Liu Hsu has made significant and fundamental contributions to the areas of adaptive control and variable structure sliding mode control and their application to robotics. Although we personally knew all these results, it was heartening to hear high praise for his work from central figures at many controls conferences. His contributions are documented in over 250 technical papers. The scholarly accomplishments go beyond being an innovative researcher, but also an inspiring mentor and dedicated teacher. He has graduated more than 25 PhD students. Most of them hold academic positions in Brazil and abroad. For his contributions to engineering education and research, Professor Liu Hsu has been recognized with the highest faculty awards in Brazil: 2008 Grand-cross medal by ONMC (Brazilian National Order of Scientific Merit) and 2005 Commander medal by ONMC. In 2011, he received from CAPES (Brazilian Coordination for the Improvement of Higher Level Personnel) the National Award of Best Thesis Advisor in Electrical Engineering. Over long periods, he performed, with efficiency and objectivity, organizing duties in IEEE CSS Technical Committee on Variable Structure Systems and Sliding Mode Control and also in Brazilian Academy of Sciences.

In what follows, we briefly recall the contents of the 23 contributions of this double special issue. The list of collaborators includes well-known researchers in adaptive control and variable structure systems, which are colleagues, co-authors, and former doctoral students of Professor Liu Hsu.

The paper [3] by Zhu, Krstic, Su, and Xu presents a variation on adaptive backstepping output feedback control design for uncertain minimum-phase linear systems. Unlike the traditional nonlinear design, the proposed control method is linear and Lyapunov based without utilizing over-parameterization, tuning functions, or nonlinear damping terms to address parameter estimation error. Local stability of the closed-loop system and trajectory tracking are guaranteed.

Hypersonic missile control in the terminal phase is addressed by Yu, Shtessel, and Edwards in [4] using continuous adaptive higher order sliding mode (AHOSM) control with adaptation. The AHOSM self-tuning controller is proposed and studied. The double-layer adaptive algorithm is based on equivalent control concepts and ensures non-overestimation of the control gain to help mitigating control chattering.

In [5], Barkana has developed adaptive controllers to guarantee stability and asymptotically perfect tracking under ideal conditions. In particular, the simple adaptive control methodology has been developed to avoid the use of identifiers, observer-based controllers, and in general, to avoid using large-order adaptive controllers in the control loop. This paper revisits and modifies the use of various components of the simple adaptive control approach and shows how one can use passivity concepts such that, while it maintains robustness with disturbances, it also allows asymptotically perfect tracking in ideal conditions.

The paper [6] by Geromel, Deaecto, and Colaneri introduces and focuses on a new control strategy for continuous-time Markov jump linear systems—denominated minimax control. It generalizes switching and linear parameter varying control strategies and is determined such as to preserve stochastic stability and guaranteed \mathcal{H}_2 performance. The special classes of Markov mode-dependent and mode-independent control are considered. The design methodology is characterized by minimax problems for which the existence of a saddle point is the central issue to be taken into account.

In the paper [7] by Bartolini, Estrada, and Punta, the output-tracking problem for a class of non-affine nonlinear systems with unstable zero-dynamics is addressed. The system output must track a signal, which is the sum of a known number of sinusoids with unknown frequencies amplitudes and phases. The non-minimum phase nature of the considered systems prevents the direct tracking by standard sliding mode methods, which are known to generate unstable behaviors of the internal dynamics. The proposed adaptive indirect method relies on the properties of differentially flat systems between the original output and a suitably designed flat output.

In the paper [8] by Oliveira, Peixoto, and Nunes, it is proposed an adaptive output-feedback controller for uncertain linear systems without a priori knowledge of the plant high-frequency gain sign. To deal with parametric uncertainties and unmodeled dynamics, the authors consider a robust adaptive strategy named binary model reference adaptive control. The effective way of tackling unknown high-frequency gain sign is employing monitoring functions. The developed adaptive control guarantees global exponential stability of the closed-loop error system with respect to a compact residual set.

Wen, Tao, and Liu have developed in [9] adaptive control schemes for uncertain multivariable systems with unmatched input disturbances and are applied to an aircraft flight turbulence compensation problem. Key relative degree conditions from system input and disturbance are derived in terms of system interactor matrices for the design of a nominal state or output feedback control law that ensures desired asymptotic output tracking and disturbance rejection. All closed-loop system signals are bounded, and the system output tracks a reference output asymptotically despite the system and disturbance parameter uncertainties.

Unlike previous works on high-gain observers, the focus of the paper [10] by Prasov and Khalil is the effect measurement noise has on the tracking error, not the estimation error. Although a tradeoff exists between the speed of state reconstruction and the bound on the steady-state estimation error, such a compromise is not evident in the tracking error of the first state. This work provides the relationship between the high-gain observer parameter and the tracking error and its subsequent derivatives.

The paper [11] by Cardim, Teixeira, Assunção, Ribeiro, Covacic, and Gainois concerns with the design of variable structure controllers for uncertain switched linear plants. The proposed method is based on Lyapunov–Metzler inequalities and on properties of strictly positive real (SPR) systems, with the advantage that it can be applied in control of uncertain switched linear system. Examples illustrate the effectiveness of the robust control system, including applications of the proposed methods in the design of switching control strategies for active suspensions systems in road vehicles.

In the work [12] by Leite and Lizarralde, the 3D visual tracking problem is considered for a robot manipulator with uncertainties in the kinematic and dynamic models. The visual feedback is provided by a fixed and uncalibrated camera located above the robot workspace. Adaptive visual servoing schemes, based on a kinematic approach, are developed for image-based look-and-move systems allowing for both depth and planar tracking of a reference trajectory, without using image velocity and depth measurements. In order to include the robot dynamics in the presented solution, a cascade control strategy is developed based on an indirect/direct adaptive method.

The paper [13] by Incremona and Ferrara addresses the design of a model-based event-triggered sliding mode control strategy of adaptive type. The overall proposal can be regarded as a networked control scheme, because one of the design objectives is to reduce the number of transmissions of the plant state over the network used to construct the control loop. The key idea consists in using the actual plant state or the state of a suitably updated nominal model of the plant to generate the control variable, depending on the magnitude of the sliding variable.

A variable structure model-reference adaptive control of impedances and admittances – driving-point (DP) functions – is proposed in [14] by Cunha and Costa. Only voltage and current measurements are required to implement the controllers. The inclusion of a prefilter in the reference model allows the synthesis of quite general DP functions, even with nonminimum phase zeros and unstable poles. It is shown that the stability of the closed-loop system depends only on the source DP function and the chosen reference model.

In the paper [15] by Liu, Yang, and Lin, an adaptive output feedback control scheme is proposed for a class of nonlinear systems with possible actuator failures. The system not only

involves unknown parameters but also takes nonlinear terms linear in the unmeasured states into account and is preceded by hysteretic actuators whose nonlinearities are characterized by the saturated Prandtl–Ishlinskii model. By developing a high-gain observer with one dynamic gain, the closed-loop stability and arbitrarily small tracking error can be guaranteed.

The paper [16] by Kallakuri, Keel, and Bhattacharyya presents new methodologies to design a set of controllers such that every controller in the set preserves closed-loop stability of a given multivariable plant under prescribed loop failures. The methods are strictly based on frequency response data of the plant that can be easily measured by experiments.

In the paper [17], Julius, Zhang, Qiao, and Wen present a new multi-input adaptive notch filter algorithm that can be used to extract the periodic components from multiple circadian signals simultaneously. Once the periodic components are extracted, the next step is to relate their phases with the circadian phase. For this, the authors propose a nonlinear observer, which is based on a model of the circadian phase dynamics widely used in the study of biological oscillators.

The work [18] by Dias, Queiroz, Araujo, and Dias proposes a control structure to be applied to robotic manipulators. The proposed controller can be divided into two parts. The first one is a left inverse system, which is used to decouple the dynamic behavior of the joints. The second is a sliding mode controller, which is applied for each decoupled joint. The proposed structure used only input/output measurements, reduces the control signal chattering, and it is robust to uncertainties.

The paper [19] by Alves, Teixeira, De Oliveira, Cardim, Assunção, and De Souza considers a class of uncertain nonlinear systems described by Takagi–Sugeno (T-S) fuzzy models with matched uncertainties and disturbances. Considering the plant is subject to actuator saturation, a switched control design method is proposed such that the equilibrium point of the controlled system is locally asymptotically stable, for all initial conditions in a region obtained in the design procedure. An exact representation of the minimum function using signal functions is presented. Therefore, it is offered a bridge between the switched control and variable structure control laws, because they are usually based on minimum and signal functions, respectively.

In the paper [20] by Bobtsov, Pyrkin, and Ortega, a new class of estimators for permanent magnet synchronous motors is proposed. Using a novel representation of the permanent magnet synchronous motor dynamics and some suitable filtering, the authors obtain new solutions to the problems of identification of the stator resistance–inductance and flux estimation with known electrical parameters.

The paper [21] by Bhaya and Kaszkurewicz views the classical Chiu–Jain algorithm, originally proposed for congestion control of network links, as a decentralized algorithm for the fair allocation of a total of units of a shared resource among users. A new analysis is given of the general case of additive increase and multiplicative decrease (AIMD) dynamics, from the perspective of virtual equilibria and variable structure systems, leading to a better understanding of the Chiu–Jain algorithm, which is one example of AIMD dynamics. Subsequently, a new adaptive version of the algorithm, called adaptive AIMD, is described, with the same property of converging to the fair share, without assuming that it is known.

The paper [22] by Menon, Edwards, and Shtessel considers the problem of reconstructing state information in all the nodes of a complex network of dynamical systems. A supervisory adaptive sliding mode observer configuration is proposed for estimating the states. A linear matrix inequality (LMI) approach is suggested to synthesize the gains of the sliding mode observer. Although deployed centrally to estimate all the states of the complex network, the design process depends only on the dynamics of an individual node of the network.

The main contribution of the paper [23] by Chriette, Plestan, Castañeda, Pal, Guillo, Odelga, Rajappa, and Chandra is to propose a scheme of attitude controller for a class of unmanned aerial vehicles based on an adaptive version of the super-twisting algorithm. The adaptive gain allows to design the controller without knowing bounds of the uncertainties and perturbations. This controller is validated by experimental results.

The paper [24] by García-Carrillo, Vamvoudakis, and Hespanha proposes a new approximate dynamic programming algorithm to solve the infinite-horizon optimal control problem for weakly coupled nonlinear systems. The algorithm is implemented as a three-critic/four-actor

approximators structure, where the critic approximators are used to learn the optimal costs, while the actor approximators are used to learn the optimal control policies.

An adaptive second-order sliding mode output feedback controller is developed by Negrete-Chávez and Moreno in [25] to deal with the case that the bound of the uncertainty/perturbation is unknown. The control structure consists in a twisting controller and a super-twisting observer to estimate the unmeasured variable. The gains of the controller and observer are parameterized in terms of a scalar gain, such that increasing these two gains, it is always possible to find values to (finite-time) stabilize the closed-loop system. The main technical contribution of the paper is to give a sound and non-trivial Lyapunov analysis of this otherwise intuitively simple idea.

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REFERENCES

1. Casavola A, Hespanha J, Ioannou P. Recent trends on the use of switching and mixing in adaptive control. *International Journal of Adaptive Control and Signal Processing* 2012; **26**(8):690–691.
2. Sun J, Krstic M, Bekiaris-Liberis N. Robust adaptive control: legacies and horizons. *International Journal of Adaptive Control and Signal Processing* 2013; **27**(1/2):1–3.
3. Zhu Y, Krstic M, Su H, Xu C. Linear backstepping output feedback control for uncertain linear systems. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1080–1098.
4. Yu P, Shtessel Y, Edwards C. Continuous higher order sliding mode control with adaptation of air breathing hypersonic missile. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1099–1117.
5. Barkana I. Robustness and perfect tracking in simple adaptive control. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1118–1151.
6. Geromel JC, Deaecto GS, Colaneri P. Minimax control of Markov jump linear systems. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1152–1162.
7. Bartolini G, Estrada A, Punta E. Adaptive tracking of sinusoids with unknown frequencies for some classes of SISO non-minimum phase systems. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1163–1183.
8. Oliveira TR, Peixoto AJ, Nunes EVL. Binary robust adaptive control with monitoring functions for systems under unknown high-frequency-gain sign, parametric uncertainties and unmodeled dynamics. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1184–1202.
9. Wen L, Tao G, Liu Y. Multivariable adaptive output rejection of unmatched input disturbances. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1203–1227.
10. Prasov AA, Khalil HK. Tracking performance of a high-gain observer in the presence of measurement noise. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1228–1243.
11. Cardim R, Teixeira MCM, Assunção E, Ribeiro JMSM, Covacic R, Gaino R. Robust switched control based on strictly positive real systems and variable structure control techniques. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1244–1268.
12. Leite AC, Lizarralde F. Passivity-based adaptive 3D visual servoing without depth and image velocity measurements for uncertain robot manipulators. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1269–1297.
13. Incremona GP, Ferrara A. Adaptive model-based event-triggered sliding mode control. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1298–1316.
14. Cunha JPVS, Costa RR. Model-reference impedance and admittance control of linear systems. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1317–1332.
15. Liu Y, Yang Z, Lin Y. Adaptive failure compensation of hysteretic actuators for a class of nonlinear systems via output feedback. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1333–1354.
16. Kallakuri PS, Keel LH, Bhattacharyya SP. A measurement-based approach to designing fault-tolerant controllers for multivariable systems. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1355–1374.
17. Julius A, Zhang J, Qiao W, Wen JT. Multi-input adaptive notch filter and observer for circadian phase estimation. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1375–1388.
18. Dias S, Queiroz K, Araujo A, Dias A. Robust control of robotic manipulators based on left inverse system and variable structure model reference adaptive control. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1389–1407.
19. Alves UNLT, Teixeira MCM, De Oliveira DR, Cardim R, Assunção E, De Souza WA. Smoothing switched control laws for uncertain nonlinear systems subject to actuator saturation. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1408–1433.

20. Bobtsov A, Pyrkin A, Ortega R. A new approach for estimation of electrical parameters and flux observation of permanent magnet synchronous motors. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1434–1448.
21. Bhaya A, Kaszkurewicz E. A decentralized adaptive algorithm for fair allocation of a shared resource. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1449–1464.
22. Menon PP, Edwards C, Shtessel YB. Adaptive sliding mode observation in a network of dynamical systems. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1465–1477.
23. Chriette A, Plestan F, Castañeda H, Pal M, Guillo M, Odelga M, Rajappa S, Chandra R. Adaptive robust attitude control for UAVs – design and experimental validation. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1478–1493.
24. García-Carrillo LR, Vamvoudakis KG, Hespanha JP. Approximate optimal adaptive control for weakly coupled nonlinear systems: a neuro-inspired approach. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1494–1522.
25. Negrete-Chávez DY, Moreno JA. Second-order sliding mode output feedback controller with adaptation. *International Journal of Adaptive Control and Signal Processing* 2016; **30**(8–10):1523–1543.

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