Guest Editorial
Special Issue on Applied LPV Modeling and Identification

IN A SIGNIFICANT number of engineering applications, control systems must be designed in order to guarantee the satisfactory closed-loop operation of a given plant in many different operating conditions. The Linear Parametrically Varying (LPV) framework was proposed almost 20 years ago as a way of coping systematically with such design problems.

LPV modeling can be viewed in a number of different perspectives, which consequently lead to a number of different approaches. More precisely, two broad classes of methods can be distinguished in the literature.

Analytical methods, based on the availability of reliable nonlinear equations for the dynamics of the plant, from which suitable control-oriented LPV representations can be derived. The methods belonging to this class aim at developing LPV models for the plant to be controlled by resorting, broadly speaking, to suitable extensions of the familiar notion of linearization, developed in order to take into account off-equilibrium operation of the system.

Experimental methods, based entirely on identification. The methods belonging to this class aim at deriving LPV models for the plant directly from input–output data. As far as identification methods are concerned, a number of algorithms has been proposed in the literature in the last ten years or so, aiming at the estimation of the parameters for both input–output and state-space models, using many different approaches, such as subspace techniques, orthonormal basis functions, LMIs, gradient and least mean squares optimization, stochastic approximation and set membership concepts. While most LPV identification techniques are based on the assumption that the identification procedure can rely on one *global* identification experiment in which both the control input and the scheduling variables are (persistently) excited in a simultaneous way, in many applications this assumption may not be compatible with operational constraints. In this respect, it would be desirable to try and derive a parameter-dependent model on the basis of *local* experiments only, i.e., experiments in which the scheduling variable is held constant and only the control input is excited. Such a viewpoint has been considered in a number of publications, where numerical procedures for the construction of parametric models for gain scheduling on the basis of local experiments and for the interpolation of local controllers have been proposed.

From the standpoint of application, many real systems exhibit dynamics which can be reasonably described by LPV models and there is an increasing interest for this modeling and identification framework in such diverse areas as, e.g., aeronautics, space, automotive, mechanics, mechatronics, robotics, bio-engineering, process control, semiconductor manufacturing and computing systems. However, while early work dates back to the 1990s and the research activity has been continuously active since, a number of issues are still open, both in terms of the development of suitable methodologies and in terms of proving their actual applicability to real life problems. In this respect, there is a strongly felt need to investigate new approaches for dealing, in a systematic way, with the complexity and the increasingly stringent specifications arising in advanced applications.

This Special Issue aims at assessing the current state-of-the-art in the neighboring fields of LPV modeling and system identification with the objectives of revealing the synergies between the two research fields and of measuring the capability of present and future methods and tools to deal with real, challenging applications.

The first two papers cover applications in automotive vehicle dynamics, an area in which LPV modeling methods have a lot of potential in dealing with multiple operating points for the systems under study, both for analysis and synthesis. In particular, in “Direct identification of optimal SM-LPV filters and application to vehicle yaw rate estimation,” (Novara, Ruiz, and Milanese) four-wheeled vehicles are considered, the problem of developing virtual sensors for the yaw rate is studied and a solution in terms of an LPV filter is proposed, which allows the elimination of expensive physical sensors and a significant cost reduction of safety control systems. On the other hand, in “Design and validation of a gain-scheduled controller for the electronic throttle body in ride-by-wire racing motorcycles,” (Corno, Tanelli, Savaresi, and Fabbri) LPV modeling and analysis methods are used to check stability and performance of the closed-loop system, both on a test-bench employing as set-point the throttle position recorded during test-track experiments and on an instrumented motorcycle.

Moving from vehicle dynamics to infrastructure management, in the third paper, “Linear parameter varying identification of freeway traffic models,” (Luspay, Kulcsár, van Wingerden, Verhaegen, and Bokor) a non-conventional technique is proposed to transform the nonlinear freeway traffic flow model into a parameter-dependent form and a comparison with traditional nonlinear parametric identification, generally used in traffic identification, is also provided.

Mechatronic systems, with specific reference to motion systems, pose significant modeling and control design challenges, which can benefit from an LPV formulation, in which some degrees of freedom of the system are treated as parameters, thus significantly reducing the complexity of the control-oriented modeling problem. This is demonstrated in the paper

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"Interpolation-based modeling of MIMO LPV systems," (De Caigny, Camino, and Swevers), in which the so-called SMILE approach to interpolation-based LPV identification is discussed and applied to the derivation of a discrete-time interpolating LPV model for a mechatronic XY-motion system based on experimentally obtained data.

The fifth and sixth papers deal with the development of LPV models for thermal and fluid processes. In particular, in "Continuous-time linear parameter-varying identification of a cross flow heat exchanger: a local approach," (Mercère, Pálsson, and Poinot) a model for a cross flow heat exchanger is derived in LPV form, taking into account the dependency of the system's dynamics on the hot and the cold mass flow rates in an explicit way. In "An LPV modeling and identification approach to leakage detection in high pressure natural gas transportation networks," (Lopes dos Santos, Azevedo-Perdicoúlis, Ramos, de Carvalho, Jank, and Milhinhos) LPV model identification is exploited to derive from input-output data a mathematical model to be used for the design of a Kalman-based leakage (fault) detection system. A small section of a gas pipeline crossing Portugal in the direction South to North has been used as a case study: LPV models have been obtained from normal operation data and the proposed LPV Kalman filter-based methods have been compared with a standard mass balance method.

The field of dynamic modeling and closed-loop control of computing systems is presently very active, and can benefit significantly from the LPV framework, as such systems exhibit dynamics which are strongly affected by external parameters such as, e.g., the arrival rate and service time of Web applications. In particular, black-box techniques are specially suitable for such applications, as there is little or no prior knowledge to be exploited in the modeling phase. In "Identification of LPV state-space models for Autonomic Web service systems" (Tanelli, Ardagna, and Lovera) black-box LPV state-space models are identified to describe the dynamics of Web service systems under the effect of different control variables such as admission control, dynamic voltage scaling, and resource allocation in virtualised systems.

The application area which motivated most of the initial developments in LPV modeling and control is the aerospace one. Indeed, aircraft, rotorcraft and space vehicles are required to operate in a wide range of flight conditions, so that the use of parameter-dependent models seems a very natural approach for such systems. In this Special Issue, three papers deal with various aspects of aerospace applications. In particular, the paper "Development of an integrated LPV/LFT framework: Modeling and data-based validation tool" (Szabó, Marcos, Mostaza, Kerr, Rödönyi, Bokor, and Bennani) is motivated by space applications and presents a set of tools for LPV modeling, the technical readiness of which is exemplified through the development of validated Linear Fractional Transformation (LFT) models used for LPV control design and analysis of a nonlinear longitudinal model of the NASA HL-20 reentry vehicle. The tools described in the paper cover also the interesting problem of data-based validation for LPV models. In "Generation of optimal linear parametric models for LFT-based robust stability analysis and control design," (Pfifer and Hecker) and "Computation of a flexible aircraft LPV/LFT model using interpolation," (Ferreres) two approaches to the problem of generating linear parametric state-space models which can approximate a nonlinear system with high accuracy and are optimally suited for LFT-based robust stability analysis and control design are presented. Both papers are motivated by applications in aeronautics: in the first one the proposed methods are demonstrated on two industrial applications, one being a nonlinear missile model, the other a nonlinear transport aircraft model; in the second one the goal is to compute an aeroelastic parameter-dependent model in LFT form for a transport aircraft.

Not unlike data-driven model validation, another important problem in the LPV literature is model reduction. In "Frequency-weighted discrete-time LPV model reduction using structurally balanced truncation" (Abbas and Werner) the problem is studied with specific reference to discrete-time models and a frequency-weighted approach is proposed, which ensures a number of properties of the reduced order model, including guaranteed stability, provided that the full order model is stable. The approach is applied to the modeling of the beam-head assembly of an industry-grade prototype gantry robot.

Finally, in "Identification of piecewise affine LFR models of interconnected systems" (Pepona, Paoletti, Garulli, and Date) identification of discrete-time nonlinear systems with LFT structure (i.e., composed by interconnected linear time-invariant systems and static nonlinearities) is addressed and an iterative approach is adopted where standard techniques are applied to the linear subsystem, whereas recently developed piecewise-affine identification techniques are employed for modeling the static nonlinearity. The technique is demonstrated by the application to the silverbox benchmark problem.

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