[Book Review] H.K. Lam and F.H.F. Leung (2011) *Stability Analysis of Fuzzy-Model-Based Control Systems: Linear-Matrix-Inequality Approach*, Springer[1]

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Summary

The work under review is, fundamentally, a research monograph containing some of the authors' more relevant developments in the past decade. Most of it digresses around the issues of shape-dependent conditions in fuzzy control.

Indeed, this book considers models in Takagi-Sugeno (TS) form subject to fuzzy control laws with, in principle, different controller membership functions to that of the process. The leitmotif of the book is introducing shape-dependence by exploiting some inequality conditions on controller and process memberships (which are assumed to be known *a priori*) which, explicitly, do *not* hold in the whole standard simplices, where the memberships in TS models lie. In this way, some conservativeness of fuzzy control analysis can be removed: instead of discussing properties for *all* plants in a fuzzy polytope, a subset of them can be excluded.

A beginning Ph. D. student looking for an alternative to the seminal book by Tanaka to get fast into state-of-the art of fuzzy control will be disappointed because the book is not so easy to read (preliminary material is not self-contained) and the motivational part is, intentionally, not focused towards a student audience trying to grasp generic ideas and practical applications. For them, this book must be left for a second reading even if the title might seem to indicate the contrary.

Notwithstanding, a researcher interested in shape-dependent conditions for fuzzy control will find this book interesting as a reference material. It's almost equivalent to carrying around a collection of a dozen key papers from the authors but, well,

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the selection has already been made and it is representative. For such audience, my opinion is that chapters 3, 5, 6, 9 and 10 convey the most elegant and interesting results.

In summary, although this is not the book that every researcher in a fuzzy research team should have on its bookshelf, the book will prove valuable in the Department bookshelf as a reference in shape-dependent designs for advanced Ph.D. students/researchers.

Let me now comment the book contents with more detail, chapter by chapter.

Chapter content

Chapter 1 deals with a short review of many literature results. Only a textual account and enumeration is given, hence the chapter is of very little use apart from the selection of references.

Chapter 2 presents a PDC-like fuzzy controller and quadratic stability conditions. It starts with a very-conservative shape-independent condition which cannot surpass the performance of a linear controller. When controller and plant memberships are coincident (as commonly assumed in most literature), relaxations to the well-known double-sum expressions appearing in the stability conditions are enumerated until the asymptotic “Polya” ones are reached. As in the previous chapter, everything is enumerated with barely any explanation, motivation or proof so the uninformed reader will not increase his background on these key topics unless the cited references are consulted in depth.

Chapter 3 discusses quadratic Lyapunov functions in the context of imperfect matching of controller and process memberships (m_i and w_i, respectively). If some linear inequalities $m_i - \rho_i w_i + \delta_i \geq 0$ can be stated (these inequalities introduce *shape-dependency* because they are not fulfilled for arbitrary m, w), then some theorems ensue, both for stability and quadratic integral cost bounds (guaranteed-cost control). Later on, “staircase” piecewise-constant approximations of the process memberships in the controller ones are discussed based on related grounds. The inequalities are posed in the middle of some technical conditions, but a reader unfamiliar with the procedures will not clearly grasp how ρ_i, δ_i and m_i are crafted; in fact, as the best choice for controller memberships is almost always $m_i \equiv w_i$, there is reduced practical application of the proposals in the chapter. The most interesting application is uncertain knowledge of the process memberships, which is discussed on Chapter 10.

Chapter 4 presents a new non-PDC controller structure. However, the resulting conditions even assuming a simple quadratic Lyapunov function are nonconvex bilinear matrix inequalities in both the stability and guaranteed-cost setups presented. A genetic-algorithm based is presented to solve such nonconvex setup. There are two caveats: (*a*) BMI-solving with directed random search is orders-of-magnitude less efficient than convex optimization and have local minima; also, there are other possibilities and conservative relaxations for solving the BMIs in literature; (*b*) there are very few control problems which *cannot* be cast as BMIs: once BMIs are allowed, other controller, Lyapunov function families, output feedback, structured feedback matrices, can be easily cast as BMI.

Chapter 5 proposes a more interesting controller, incorporating a nonquadratic Lyapunov function and derivatives of the memberships. However, the requirement that some scalars ρ and σ_i are known *a priori*, such that $w_i + \rho \dot{w}_i + \sigma_i \geq 0$ limits the approach as $\dot{w}_i$ depends on $\dot{x}$ which, in general, depends on the to-be-computed control action. So, ρ and σ_i can be reliably computed only on those memberships whose arguments' derivative does not depend on u. Even with this limitation, the results are much more interesting (convex LMI) and elegant.

Chapter 6 presents the idea of switching controllers in different regions of the operational space. In this way, a different set of shape-related constants similar to those discussed in Chapter 3 can be cast for each region, with different controller gains, too. This interesting idea removes conservativeness (at the expense of bigger triple-sum LMI conditions and possible sliding modes).

Chapter 7 further extends the idea by actually considering that even the original fuzzy model can be different on different regions. The authors propose combining "local" models (equivalent to the plant in smaller subsets, hence with "closer" consequent vertices) and global ones (i.e., the only ones considered up to this point). However, in order to further develop the results, they introduce the very conservative assumption that the only nonlinearity in the control action effect B_i is a scalar one $B(x) = \alpha(x) B_m$, $\alpha(x) \in \mathbb{R}$. Then, the authors set up a global sliding-mode-based switching controller plus a local non-switching one.

Chapter 8 presents a couple of results that apply to fuzzy systems with time-delay. It's a reasonable tutorial approach to introducing the delay-induced issues in fuzzy systems. However, the area of time-delay systems is quite an active one at this moment and a whole book could have been written on it; many LMI results in non-fuzzy *linear* delay systems can be "fuzzified" by just replacing a model matrix, say A, with vertex matrices A_i. Anyway, the chapter is well written and of recommendable reading.

Chapter 9 discusses sampled-data fuzzy systems in which the control is evaluated only at sampling instants, whereas the process is continuous. The closed-loop expressions involve equations where the controller memberships and state feedback are evaluated at the last sample instant $(m_j(t_\gamma), x(t_\gamma))$, but process dynamics is continuous-time ($w_i(t)$). As the result is a delay system, results related to those in Chapter 8 can be applied. However, it is a well-known fact that, if no relationship between $w_i(t)$ and $m_j(t_\gamma)$ is plugged in, the results cannot be better than a linear regulator; this is why an inequality $m_i(t_\gamma) - w_i(t) + \delta_i \geq 0$ is assumed to hold and results akin to those in chapter 3 are provided. Obtaining δ_i in a particular problem is, however, tricky, and only discussed in a paragraph of a numerical example.

Chapter 10, the last one, discusses "type-2" fuzzy control systems. I think that the authors' approach to type-2 LMI fuzzy control is basically the only viable way: use interval-uncertainty information on the memberships to set up linear inequalities as presented on Chapter 3. So, in my opinion, the contents written in this chapter simultaneously "open" and "close" the Takagi-Sugeno Type-2 LMI fuzzy control problem.