The Future of Control and Automation
- A Personal Perspective in Model Based Fuzzy Control

Gang FENG
City University of Hong Kong

Outline
- Brief history of control
- Challenges for future control
- Model based fuzzy control

Brief history of control
- Early applications
  Power systems, process control, vehicle control, communication
- Early theory/tools
  Classical control theory: stability theory, PID control, design theory

Brief history of control
- Later applications
  space, military, automotive, manufacturing
- Later theory/tools
  Modern control theory: optimal control, Kalman filtering, adaptive control, robust control

Challenges for future control
- Current/future applications
  Networked systems, Nano devices/systems, biological systems, complex systems
- New theory /tools?
  Autonomous, distributed, learning, cognition safety, reconfiguration

Challenges for future control
- Control
  Engineering, Nature, Communication, Computing
  Mathematics, Physics
**Approaches to fuzzy control**

- Conventional fuzzy logic control
- Fuzzy PID
- Neuro-fuzzy control or fuzzy-neuro control
- Adaptive fuzzy control
- T-S fuzzy model based control

**T-S model based FLC**

**Motivations:**

- Conventional fuzzy control lacks systematic guidelines
- Many nonlinear systems are linear in local regions
- T-S fuzzy systems are universal function approximators
- There are many mature design techniques in conventional control

**Fuzzy model based control**

**Basic idea:**
Taking advantages of both conventional control theory and fuzzy logic theory

**Fuzzy dynamic model or T-S model**

\[ R_i : \text{If } z_i \text{ is } F_i^l \ldots \text{ AND } z_i \text{ is } F_i^r \]
\[ \text{Then } \]
\[ x(t+1) = A_i x(t) + B_i u(t) \]
\[ y(t) = C_i x(t) \]
\[ l = 1, 2, \ldots, m \]

**Global dynamic fuzzy model**

\[ x(t+1) = A(\mu)x(t) + B(\mu)u(t) \] (2)
\[ y(t) = C(\mu)x(t) \]
\[ A(\mu) = \sum_{j=1}^{m} \mu_j A_j, \quad B(\mu) = \sum_{j=1}^{m} \mu_j B_j, \quad C(\mu) = \sum_{j=1}^{m} \mu_j C_j \]

**Key features of T-S fuzzy models**

- T-S fuzzy model includes two kinds of knowledge: Qualitative and quantitative
- The model has the structure of a two level control system
- Universal function approximators
Advantages of T-S fuzzy models

- It provides a basis for systematic and rigorous analysis and synthesis of fuzzy control systems
- It provides an approach to dealing with more complex nonlinear control systems via well-established control theory and techniques.

Model based fuzzy control

- Common quadratic Lyapunov functions (CQLF)
- Piecewise quadratic Lyapunov functions (PQLF)
- Fuzzy quadratic Lyapunov functions (FQLF)
- Other approaches: linear Lyapunov functions…

First challenge

- Issue arising from boundaries of PQLFs

Discrete time systems:

\[ A_k^T P_j A_k - P_j < 0 \quad l \in \mathbb{L}, \quad k \in K(l) \]

\[ A_k^T P_j A_k - P_j < 0 \quad (l, j) \in \mathbb{N} \quad k \in K(l) \]

Continuous time systems:

\[
V(x) = \begin{cases} 
  x^T P_1 x & x \in S_l, l \in L_0 \\
  x^T P_1 x & x \in S_l, l \in L_1
\end{cases}
\]

\[
P_l = F_l^T F_l, \quad l \in L_0
\]

\[
\bar{P}_l = \bar{F}_l^T \bar{F}_l, \quad l \in L_1
\]

\[
\bar{F}_l x = \bar{F}_l \bar{x}, \quad x \in S_l \cap S_j
\]

First challenge

- Controller design via PQLFs for discrete time systems can be cast as LMIs
- Controller design via PQLFs for continuous time systems can only be cast as BMIs

How to formulate controller design as LMIs?
Second challenge

• Issue arising from FQLFs

Discrete time systems:
\[ V(x) = \sum_{j=1}^{m} \mu_j(x)x^T P x \]
Conservative!
\[ A_j^T P_j A_j - P_j < 0 \quad j, l \in L \]

Second challenge

Continuous time systems:
\[ V(x) = \sum_{j=1}^{m} \mu_j(x)x^T P_j x \]
\[ \mu \rightarrow \frac{\partial \mu}{\partial x} \rightarrow \text{Difficulty} \]
How to deal with the resulting difficulty?

Third challenge

\[ \dot{x}(t) = f(x(t), u(t)) \quad u(t) = g(x(t)) \]
Stable closed loop system

Does there exist a fuzzy controller \( u(t) = \hat{g}(x(t)) \) ?
\[ \dot{x}(t) = f(x(t), \hat{g}(x(t))) \]
Stable closed loop system

Fourth challenge

\[ x(t + 1) = \sum_{j=1}^{m} \mu_j A_j x(t) + \sum_{j=1}^{m} \mu_j B_j u(t) \]
CQLFs: No information of membership functions is used
PQLFs: Partial information of membership functions is used
FQLFs: Partial information of membership functions is used

How to use as much information of T-S fuzzy systems as possible?

Fifth challenge

Whether can fuzzy controllers, which are designed to stabilize T-S fuzzy models, stabilize the original nonlinear systems?

Other challenges

• Adaptive control based on T-S fuzzy systems
  Parameters of both membership functions and local linear systems are unknown

• Stochastic fuzzy systems
  Extra care should be exercised in deriving global models
Conclusions

• Control and other disciplines have to be considered together
• Fuzzy control provides additional tools and is complementary to conventional control
• Many challenges remain to be tackled

Thanks to All of You!