Bayesian identification of LPV-BJ models: a multidimensional kernel approach

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Motivation
Many industrial control systems exhibit nonlinear behaviour, where linear modeling is becoming insufficient to support model based control design such that the increasing performance specifications can be fulfilled. However, Linear Parameter-Varying (LPV) systems offer a powerful framework to deal with such situations while preserving the linear relationship between the input and the output signals. In this work, we introduce a nonparametric approach in a Bayesian setting to efficiently estimate, both in the stochastic and computational sense, LPV Box-Jenkins (LPV-BJ) models.

Bayesian identification for LPV-BJ systems
The one-step-ahead predictor (IIRs model form) can be written as
\[
y(k) = \sum_{l=1}^{\infty} w_l y(k-l) + \sum_{j=0}^{p-1} b_j u(k-j) + e_0(k),
\]
where \(x(k) = \{u(k), y(k), y(k-l)\}\) denotes the past measurements till time \(k\), e.g., \(u(k) = \{u(\tau)\}_{\tau \in \mathbb{R}}\) and it can be viewed as a sum of two independent zero mean Gaussian random fields \(f^*, f^0\)
\[
f = \sum_{i=1}^{\infty} f_i^* + \sum_{i=1}^{\infty} f_i^0
\]
The covariance of \(f\) should express

- coefficient functions dependency on \(p\).
- Stability of the predictor.

\[
K(x(k), x(k')) = \sum_{l=1}^{\infty} K_l^*(x(k), x(k')) + \sum_{l=1}^{\infty} K_l^0(x(k), x(k')), \quad K_l^*(x(k), x(k')) = \beta_l^* y(k-l) \exp\left(-\frac{\|y(k-l) - y(k')\|^2}{\sigma^2}\right) y(k' - l),
\]
\[
K_l^0(x(k), x(k')) = \beta_l^0 u(k-l) \exp\left(-\frac{\|y(k-l) - y(k')\|^2}{\sigma^2}\right) u(k' - l),
\]
where \(\beta_l^* = \lambda l e^{-\lambda l}\) and \(\beta_l^0 = \lambda l e^{-\lambda l}\) are the so-called decay terms. The hyperparameters are \(c_0, \sigma, \lambda_1, \lambda_2, \lambda_3, \lambda_4 \in \mathbb{R}^+\). These unknown hyperparameters are tuned using marginal likelihood maximization.

Simulation example
The coefficient functions of the process part of the considered example are
\[
\begin{align*}
a_1() &= 0.1 p^2(k-1), & a_2() &= \tan^{-1}(p(k-1)) \cos(p(k-2)), \\
b_0() &= -\exp(-p(k)), & b_1() &= 1 - 0.5 p^2(k) + p(k-1), \\
b_2() &= \tan^{-1}(p(k-2)).
\end{align*}
\]
The noise process \(n(k)\) is a colored noise generated by an LPV-ARMAX filter with coefficient functions
\[
\begin{align*}
c_0() &= 0.8 p^2(k-1), & c_4() &= 0.5 \tan^{-1}(p(k-2)), \\
d_1() &= 0.2 p^3(k-1), & d_2() &= 0.5 \sin(p(k-2)).
\end{align*}
\]
The data set consists of 1000 data points with SNR = 20dB.

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