Identification of Inverse Models for Feedforward Compensation: An Optimal IV Approach

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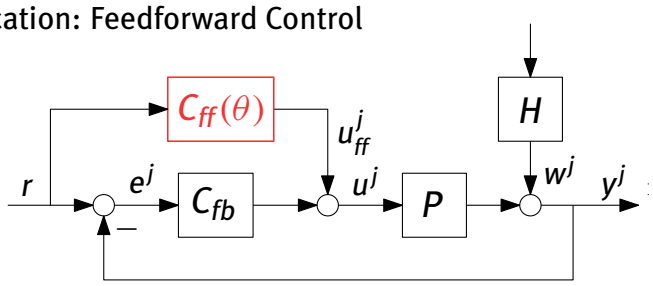
Estimation of Inverse Systems

Application: Feedforward Control



Feedforward controller $C_{ff}(q,\theta) = \dfrac{B(q,\theta)}{A(q,\theta)}$

How to maximize accuracy properties?

Estimation/Identification of inverse system P^{-1}

Measurements in a closed-loop configuration
$\Rightarrow$ Instrumental Variable approach [2]

Pursued IV Approach

IV criterion:

$$V(\theta^{j+1}) = \left\| \frac{1}{N} \sum_{t=1}^{N} z^T(t) L(q) \hat{e}^{j+1}(t, \theta^{j+1}) \right\|_W^2$$

with (filtered) r as instrument, predicted error

$$\hat{e}^{j+1}(t, \hat{\theta}^{j+1}) = \frac{1}{B(q, \hat{\theta}^{j+1})} e_m^j(t) - \varphi^T(t, \hat{\theta}^{j+1}) \hat{\theta}^{j+1}$$

and $\varphi(t, \hat{\theta}^{j+1}) = \frac{1}{B(q, \hat{\theta}^{j+1})} \begin{bmatrix} \Psi_A(q) C^{-1}(q) y_m^j(t) \\ -\Psi_B(q) e_m^j(t) \end{bmatrix}$

Key questions:

1. How to solve nonlinear optimization problem?
2. How to determine $z(t)$ and $L(q)$ for optimal accuracy?

Optimal IV for Feedforward

Closed-loop ID with BJ model structure:
$\Rightarrow$ Requires estimation of H for optimal accuracy [3]

Feedforward Control
Minimum variance feedback control: SH = 1
$\Rightarrow$ Estimating H not required for optimal accuracy

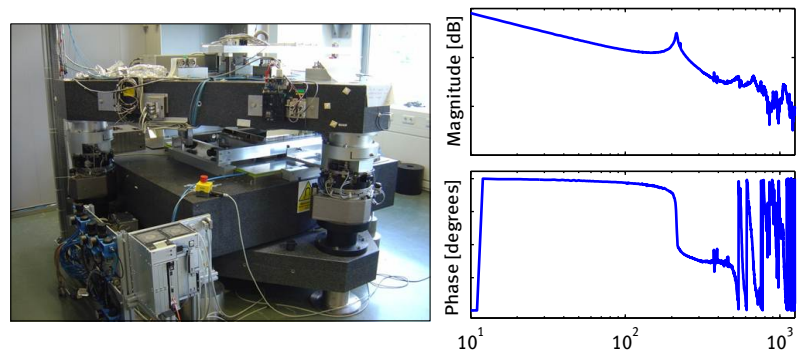
Still, $z_{\text{opt}}(t)$ depends on noise-free regressor φ_r

Pursued iterative IV approach:

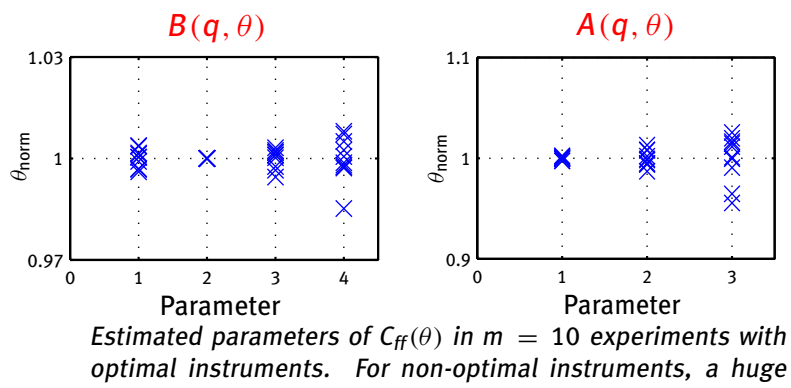
1. Deal with nonlinear optimization problem
2. Refine instrumental variables to improve accuracy

Non-causal approach (stable inversion) for NMP zeros in P

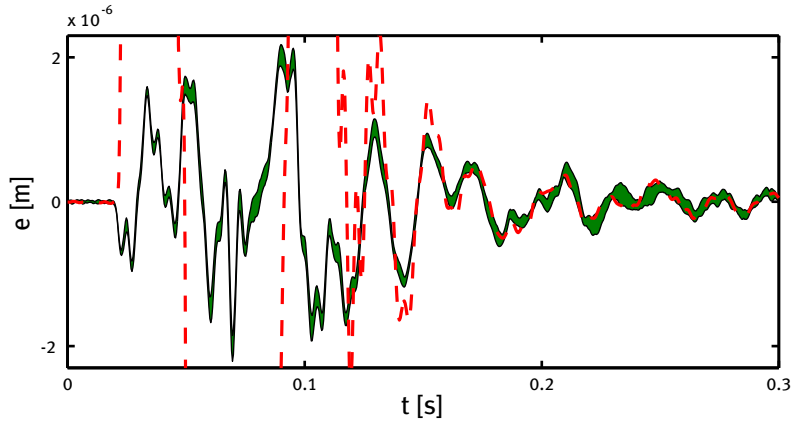
Experimental Results



Experimental setup



Estimated parameters of $C_{ff}(\theta)$ in $m = 10$ experiments with optimal instruments. For non-optimal instruments, a huge variance is obtained.



Worst-case performance based on estimated parameters in $m = 10$ experiments (green) compared to only feedback (red). Remaining repeating error: mainly cable slab.

Estimation of P^{-1} directly linked with control performance

Ongoing Research

- bias aspects in inverse model identification [5]
- MIMO systems

References

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[2] T. Söderström, P.G. Stoica and E. Trulsson, Instrumental variable methods for closed loop systems, Proc. of IFAC World Congress, 1987.
[3] M. Gilson, H. Garnier, P. Young and P.M.J. Van den Hof, Optimal instrumental variable method for closed-loop identfication, IET Control Theory and Applications, 5(10), pp. 1147-1154, 2011.
[5] Y. Jung and M. Enqvist, Estimating models of inverse systems, Proc. of the Conference on Decision and Control, Firenze, Italy, 2013.

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