Frequency Response Function-Based Iterative Control
Applied to a Nanopositioner

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Background

Iterative Learning Control (ILC) is an effective approach to achieve high tracking performance for system that perform repeating tasks [1]. Frequency Domain ILC offers practical and intuitive design rules, but requires a parametric model of the system. In contrast, Time Domain or Lifted ILC uses non-parametric models and typically results in optimal results. However, design guidelines are not transparent and accounting for robustness against plant variation is challenging. Alternatively, Data-driven methods are completely model-free, but generally take a large number of iterations to reach convergence. Although these frameworks have proven to be successful for a range of applications, it is clear that each framework has its own disadvantages. Therefore, the aim of this work is to develop an iterative control method with clear design guidelines, with fast and reliable convergence and that requires little to no modelling effort.

Approach

This achieved by combining well established results from ILC with the recent advances in Inversion-based Iterative Control (IIC) approaches [2]. The latter techniques, exploit the non-parametric FRF of the system to be controlled in order to avoid a parametric modelling effort. However, a formal connection between IIC, ILC and Repetitive Control (RC) has not yet been established and it can be shown that current approaches lack robustness and convergence speed considerations. In this work, this connection to ILC and RC is made and the insights are used to introduce robustness into the IIC approach, resulting in the following update-law regarding the Fourier coefficients of the input u,

$$U_{i+1}(\omega) = \phi(\omega)\left(U_i(\omega) + \rho(\omega) G_m^{-1}(\omega) E_i(\omega)\right). \quad (1)$$

Here, $G_m^{-1}(\omega)$ is the inverse FRF of the system and guidelines are provided on how to tune $\phi(\omega)$ to achieve robustness and fast convergence. In addition, the Model-Free IIC (MFIIC) method is considered [3], in which $G_m^{-1}(\omega)$ is estimated during each trial based on u and y, thereby completely removing the modelling effort. However, a novel convergence analysis shows that excessive learning transients may be introduced by unmeasured disturbances, which lead to unpredictable loss of performance from trial-to-trial. To alleviate this problem, an adaptive learning gain is introduced which leads to the Smoothed MFIIC update-law,

$$U_{i+1}(\omega) = U_i(\omega) + \rho_i(\omega) \frac{U_i(\omega)}{Y_i(\omega)} E_i(\omega), \quad (2)$$

where $Y_i = GU_i + D$ and $\rho_i = \tanh\left(\beta \left|\frac{Y_i}{R}\right|\right)$. The latter leads to significantly improved convergence behaviour due the absence of the blow-up behaviour as $Y_i \to 0$.

Results

The proposed approaches (blue) are compared to the traditional methods (red) by application to an experimental nanopositioner as shown in Figures 1 and 2, which shows the achieved improvements.

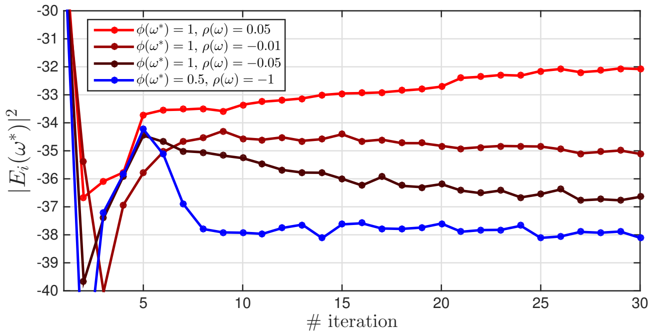

Figure 1: Faster and robust convergence is achieved by adding robustness by means of $\phi(\omega)$ in (1), visualized for the dominant frequency.

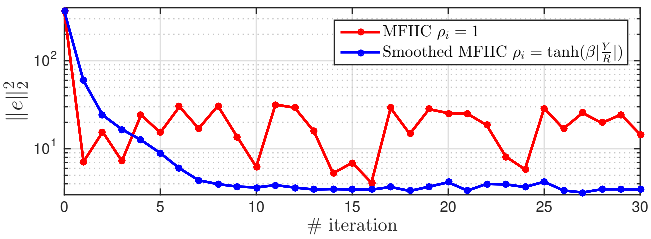

Figure 2: Reliable convergence is achieved by the adaptive learning gain ρ_i in (2), which removes the unpredictable performance loss.

References

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