Second Order Iterative Learning Control for Scale Varying Setpoints

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Introduction
Iterative learning control (ILC) [1] can achieve a high performance for repetitive setpoints. However, for different setpoints ILC should start over. In this work point-to-point movements \( r_k(t) \) with different magnitudes are considered which are constructed by scaling a nominal setpoint \( r(t) \), i.e., \( r_k(t) = T_k r(t) \). A second order ILC (SOILC) [2] method is developed to accurately track these setpoints under the influence of disturbances that are either i) constant or ii) experience the same scaling as the setpoint.

SOILC with adaptive low-pass filter in iteration domain
Consider Fig. 1 where \( C(z) \) is the controller and \( P(z) \) is the plant. A trial independent input disturbance is present, i.e., \( d_{k-1} = d_k = \cdots = d \), which models for example dry friction. The error in trial \( k \) and \( k \) can be written as

\[
e_{k-1}(t) = T_{k-1} g(t) + h(t) - S_p(z) f_{k-1}(t),
\]

(1)

\[
e_k(t) = T_k g(t) + h(t) - S_p(z) f_k(t).
\]

(2)

After trial \( k \) the terms \( g(t) = S(z) r(t) \) and \( h(t) = -S_p(z) d(t) \), with \( S(z) \) and \( S_p(z) \) being the sensitivity and process sensitivity, can be estimated using (1), (2):

\[
\hat{g}_k(t) = \frac{e_{k-1}(t) - e_k(t)}{T_{k-1} - T_k} + S_p(z) \frac{f_{k-1}(t) - f_k(t)}{T_{k-1} - T_k},
\]

\[
\hat{h}_k(t) = \frac{T_k e_k(t) - T_k e_{k-1}(t)}{T_{k-1} - T_k} + S_p(z) \frac{T_{k-1} f_k(t) - T_k f_{k-1}(t)}{T_{k-1} - T_k}.
\]

These estimations are the inputs to adaptive low-pass filters in iteration domain:

\[
\hat{g}_{k+1}(t) = (1 - \gamma_k) \hat{g}_k(t) + \gamma_k \hat{g}_k(t),
\]

\[
\hat{h}_{k+1}(t) = (1 - \gamma_k) \hat{h}_k(t) + \gamma_k \hat{h}_k(t),
\]

where \( \gamma_k = \beta |T_{k-1} - T_k| \) with an appropriate \( \beta \) such that \( 0 \leq \gamma_k \leq 1 \). Therefore, the trial independent signals \( g \) and \( h \) are estimated iteratively and used in the update law for the next feedforward in trial \( k + 1 \), i.e. \( f_{k+1}(t) = L(z)(T_{k+1} \hat{g}_{k+1}(t) + \hat{h}_{k+1}(t)) \).

Results
The proposed second order ILC method is validated in practice using the setup depicted in Fig. 2. During the learning process, different scale varying setpoints are applied under non-collocated load feedback control. The maximal absolute error is recorded and is depicted in Fig. 3 as a function of the iteration number. It can be seen that the error converges to approximately \(-45 \text{ dB}\) while different setpoints were applied. This corresponds to an accuracy of approximately one count of encoder resolution.

References