

# Control design in Hankel Iterative Learning Control

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# Control design in Hankel Iterative Learning Control

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## 1 Hankel Iterative Learning Control

Iterative Learning Control (ILC) is a control strategy used to iteratively improve the performance of a batch repetitive process by updating the command signal from one experiment (trial) to the next, using signal information of the previous trials.

Originally, ILC uses the full time span of the trial to actuate the system and measure (observe) the systems output, thereby being able to handle servo problems, i.e. problems where the system has to follow a predefined reference trajectory. Alternatively, actuation and observation during a trial can be separated, making ILC able to handle point-to-point motion control problems, [1].

**Definition** *point-to-point motion control problem.* The design of a command signal actuating the system *during* the point-to-point motion resulting the system to be positioned at the desired position without residual vibrations *after completion of the motion.*

Based on the Hankel operator properties of the system with separated actuation and observation interval, we denote ILC applied to point-to-point control problems as *Hankel ILC*.

## 2 Hankel ILC control properties

Hankel ILC can be shown to have two properties not present in the original ILC.

- Hankel ILC has the design freedom of command shaping.
- Design issues related to asymptotic stability of Hankel ILC can be handled separately from issues related to command shaping.

## 3 Hankel ILC control strategies

Independent of any control objective, asymptotic stability is an obligatory part of every ILC design method. Other ILC control design specifications are generally related to

- Robust stability, in case of unmodeled dynamics or parameter uncertainties in the system.

- Convergence speed, when optimal results should be obtained after only a few trials.
- Performance, when requirements on steady state errors are specified.

Using the additional properties in Hankel ILC we can define an additional control objective

- Command shaping, when certain command signal properties are desired.

Two control strategies for Hankel ILC are derived. Both strategies are first designed to ensure asymptotic stability of the controlled system resulting in the suppression of residual vibrations. The first control strategy is further designed to shape the command signal by minimizing the maximum amplitude of the command signal, using Linear Programming. The second strategy aims at minimizing the weighted variance of the command signal, resulting in an analytical expression for the Hankel ILC controller.

Experimental results confirm the theory behind Hankel ILC and its control design. Furthermore, they have illustrated the possibility of Hankel ILC to asymptotically converge while minimizing the command amplitude.

## References

- [1] B.G. Dijkstra & O.H. Bosgra, Exploiting Iterative Learning Control for input shaping with application to a wafer stage, *Proc. of the American Control Conference*, pp. 4811-4815, Denver, CO USA, 2003.