

ILC FOR NANOPositionING

Due to overshooting and hysteresis, the output curve from a piezoelectric actuator can differ from its input signal. The iterative learning control (ILC) method, as developed by piezosystem jena, determines the required setting curve by performing iterations and adjustments on measured curves. Besides the improvement of accuracy, ILC offers advantages such as the production of dynamic movement even above the system's resonant frequency, and flexibility regarding changing conditions of, for example, load and temperature. In addition, there is no longer a need for users to have their systems recalibrated. This brief article presents the algorithm and experimental results.

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Introduction

Founded in 1991, piezosystem jena is one of the world's leading manufacturers of piezomechanic nanopositioning systems and corresponding electronics such as piezo-drivers and amplifiers. Piezo-actuators, piezodrives, nanopositioning solutions, piezocontrollers and motion control systems are used in micro- and nanopositioning applications whenever the highest precision or high dynamics are required. In addition to a broad range of catalog products, piezosystem jena is a leader in customer-specific developments designed to provide optimised systems for very particular applications.

Piezomechanic systems are available as both open-loop systems and traditional closed-loop systems, each having their own advantages and disadvantages. The open-loop systems exhibit drift and the hysteresis phenomenon. Drift is a characteristic of piezoelectric actuators, by which a step change in the applied voltage produces an initial motion that is then followed by a small, but unintentional continuous change over a longer time scale. Hysteresis is another natural characteristic of PZT (lead zirconate titanate) ceramics. When voltage is applied in a positive direction and then in a negative direction, the movement of the actuator will not follow the same path.

Closed-loop systems compensate for these phenomena by measuring the position of the piezo and correcting for deviations. However, this process takes time and therefore reduces the maximum operating frequency, especially when compared with the speed of open-loop systems. As shown in Figure 1, the output of a piezo-actuator can be different from the input signal due to overshoot (Figure 1a) and hysteresis (Figure 1b) behaviour.

These challenges can be successfully addressed with the newly developed ILC method (as incorporated in a controller). During an initial run of the piezo, the target position and actual position are compared and the self-learning system creates a compensated input signal. The output wave is greatly improved after several iterations, which is shown in Figure 2. After the third iteration, the output wave closely matches the desired output waveform.

ILC algorithm

First of all, by using Fourier transformation, the actual position $y(t)$ is transformed to $y(j\omega)$:

$$y(t) \rightarrow y(j\omega) \quad (1)$$

The control deviation $E(j\omega)$ is then calculated by comparing the difference between the desired position $w(j\omega)$ and actual position $y(j\omega)$:

$$E(j\omega) = w(j\omega) - y(j\omega) \quad (2)$$

The next step, the improved plot history $u_{i+1}(j\omega)$ for the next iteration $i+1$, is calculated by adding up the setting curve $u_i(j\omega)$ of the current iteration i and a correction:

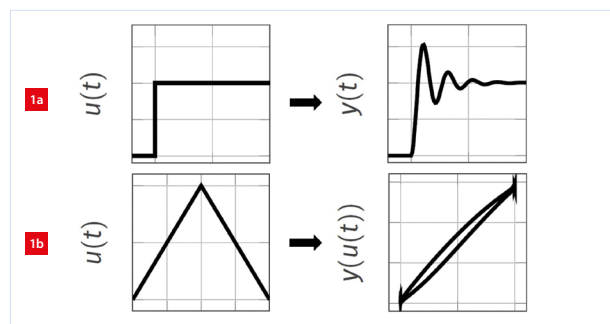
$$u_{i+1}(j\omega) = u_i(j\omega) + E(j\omega) \cdot \rho(j\omega) / G(j\omega) \quad (3)$$

Here, $G(j\omega)$ is the transfer function, which is also called the

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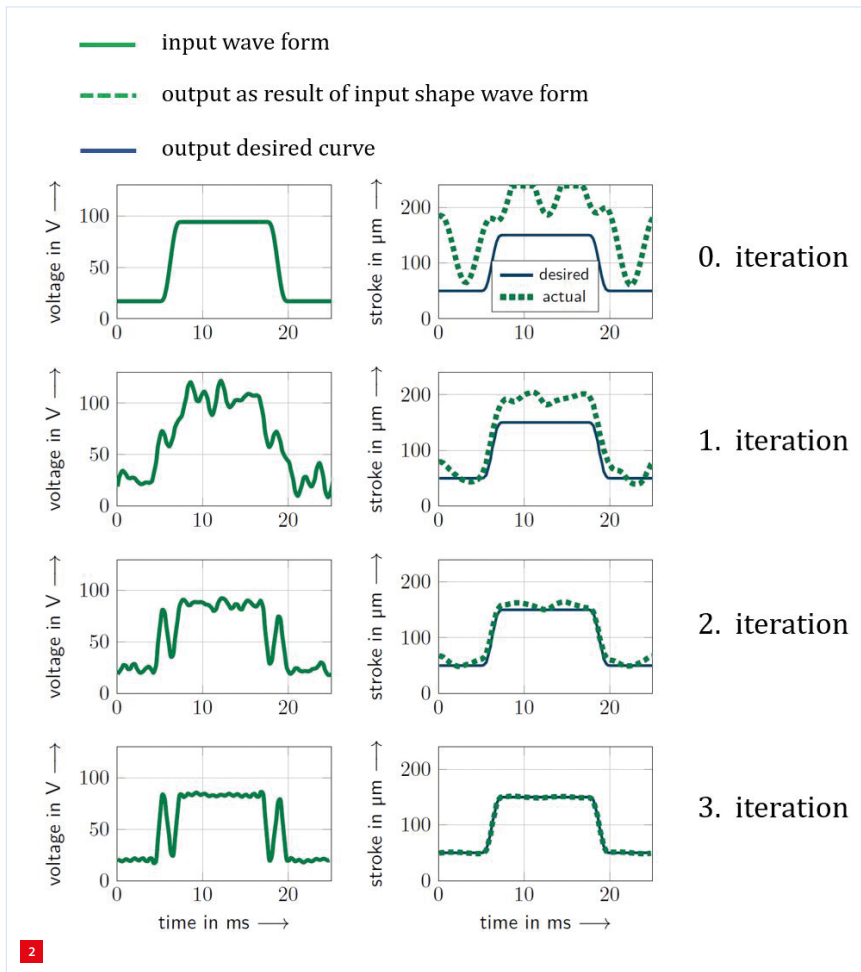
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The difference between the input signal and the output of a piezoelectric actuator.

(a) Overshoot.
(b) Hysteresis.



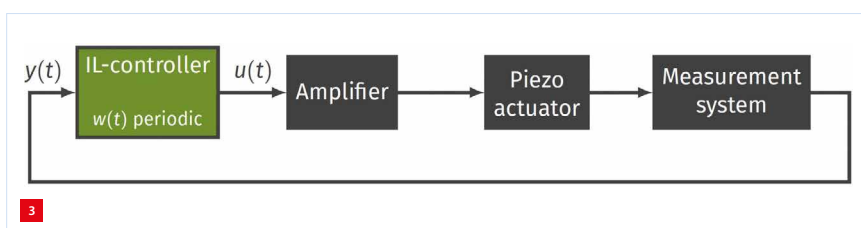
By iteratively changing the input waveform, the output waveform is greatly improved by ILC.

learning function and $\rho(\omega)$ is the learning gain. Finally, the inverse Fourier transformation is used to determine the next period and can be output from now on:

$$u_{i+1}(j\omega) \rightarrow u_{i+1}(t) \quad (4)$$

The ILC method is now given a certain number of periods for the iteration until the difference between the actual position and desired position is very small. The corresponding flowchart is shown in Figure 3.

As a result, ILC can quickly eliminate drift and hysteresis and achieve much better parameters in terms of frequency and speed compared to open-loop and traditional closed-loop systems.



The ILC flowchart.



The PX 200 CAP stage (left) with the 24DV40 controller.

Experimental results

Set-ups

As shown in Figure 4 and Figure 5, two different actuators were used for the tests to validate the ILC method. The first actuator is a PX 200 CAP stage (maximum stroke of 200 μm , 3.2 nm closed-loop resolution) with a 24DV40 controller (16-bit resolution). The second actuator is a nanoX SG stage (maximum stroke of 500 μm , 0.8 nm step resolution) combined with an ENV 800 controller (800 mA current with signal noise $< 0.3 \text{ mV}_{\text{rms}}$ @ 500 Hz).

Measurement results

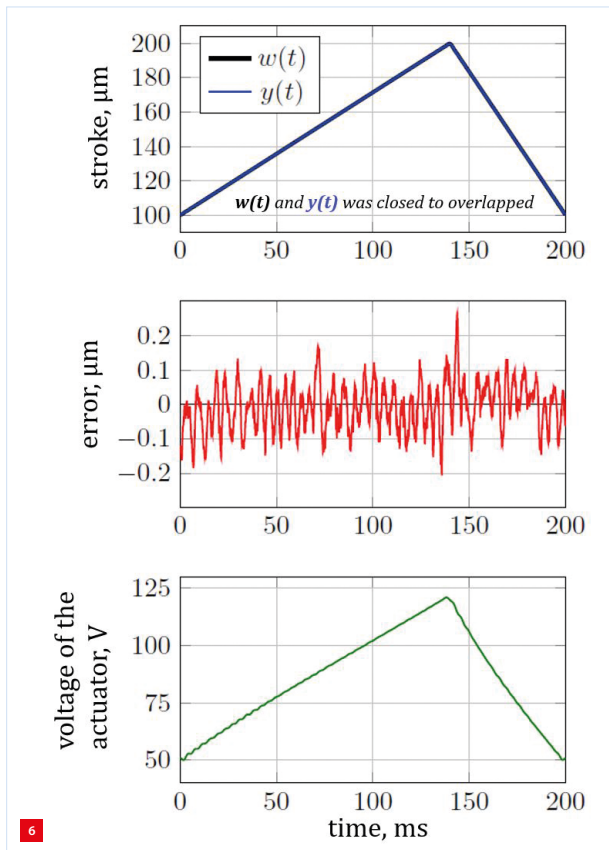
The measurement for the first set-up is shown in Figure 6. After processing by the ILC method, the actual position $y(t)$ and desired position $w(t)$ are very close to one another. The error between these two measured positions is within the 0.2 μm range. The voltage output of the piezo-actuator shows a highly similar shape compared to the curve for the desired position. Comparable results are obtained in Figure 7 for the second set-up.

Applications

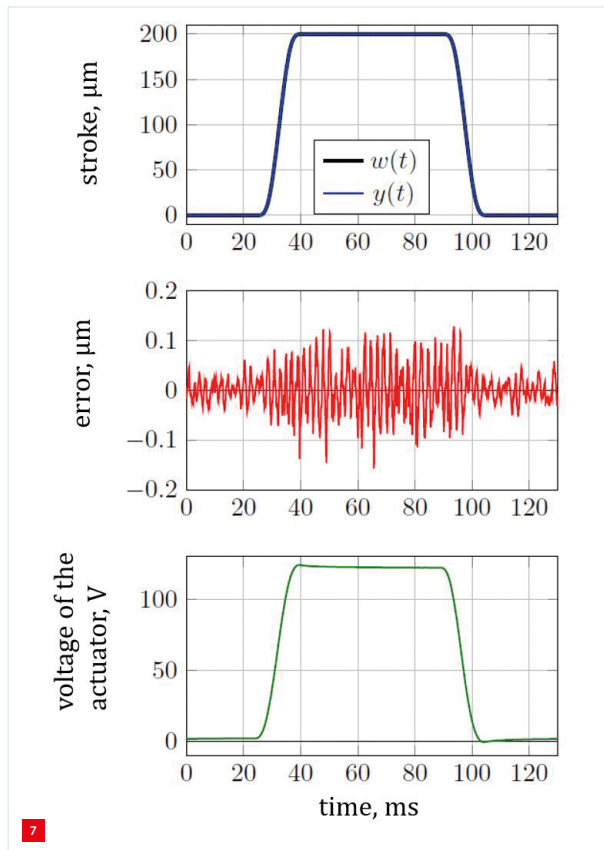
One application for ILC is the pixel-shift or micro-scanning method for high resolution. As shown in Figure 8, the scanning system vibrated in different directions, took four pictures in a very short time and with the aid of the ILC method produced a picture with much higher resolution.



The nanoX SG stage (left) with the ENV 800 controller.

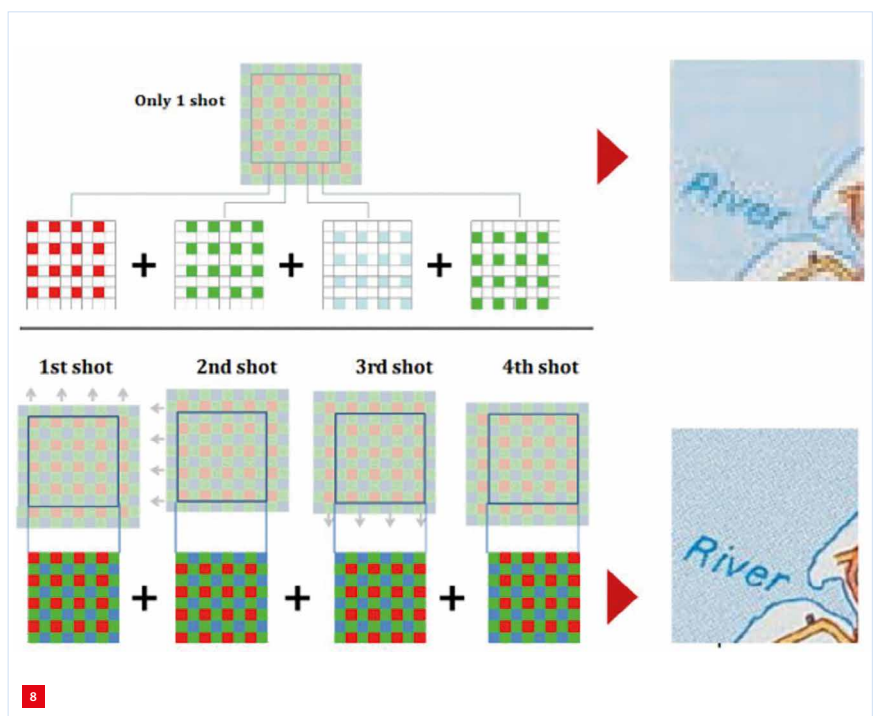


Measurement of the PX 200 CAP stage ILC-controlled using the 24DV40 controller.



Measurement of the nanoX SG stage ILC-controlled using the ENV 800 controller.

Another ILC application is concerned with a high-speed closed-loop tilting mirror for laser technology. Here, ILC enables high-frequency beam stirring by combining closed-loop repeatability with open-loop speed. The ILC method works with the closed-loop systems and digital amplifiers from piezosystem jena.



The ILC pixel-shift application showing improved image resolution in the lower image on the right.