Commutation-angle domain iterative learning control: Learning waveforms for piezo stepper actuators

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Commutation-angle domain iterative learning control: Learning waveforms for piezo stepper actuators

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Extended abstract for poster

Piezo stepper actuators are promising for high-precision motion systems due to the high resolution, high stiffness and fast response of the individual piezo elements, and the "walking" motion that enables long-stroke actuation. During the walking motion of the actuator, see Figure 1, engagement and release between the piezo elements and the mover may lead to disturbances, for example when elements are not perfectly aligned. These disturbances are non-periodic in the time domain for varying velocities, but they are periodic in the commutation-angle domain (Figure 2). Therefore, these disturbances can be compensated by optimizing the waveforms through learning from data.

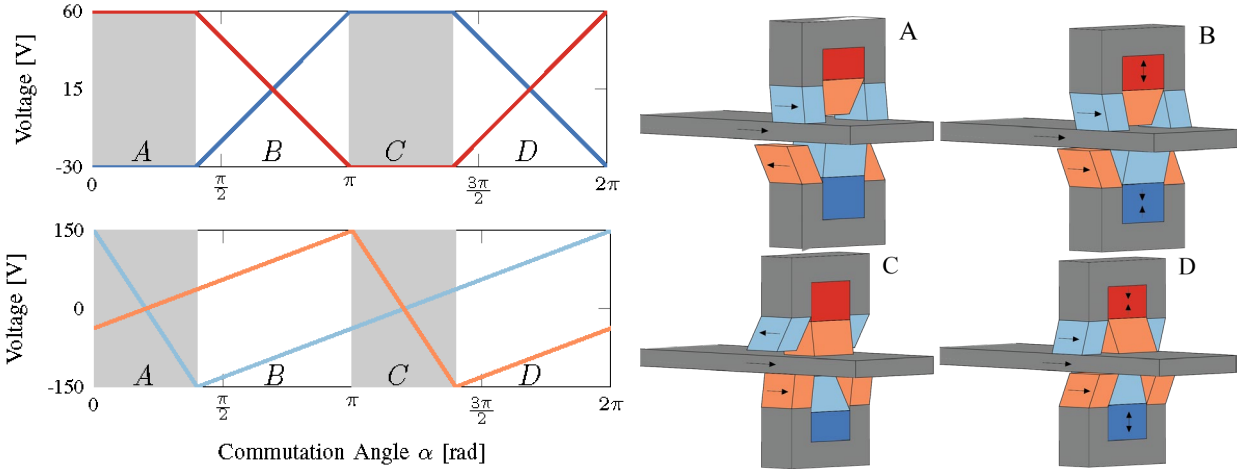

Figure 1 *Clamp (top, left) and shear (bottom, left) waveforms corresponding to the walking motion of the piezo-stepper actuator (right). The four phases of the walking motion are the following: A) the shear elements (light blue) of group 1 propel the mover forward. B) transition phase. C) the shear elements (orange) of group 2 propel the mover forward. D) transition phase. In phases A) and C), the shear elements that are not in contact with the mover are reset.*

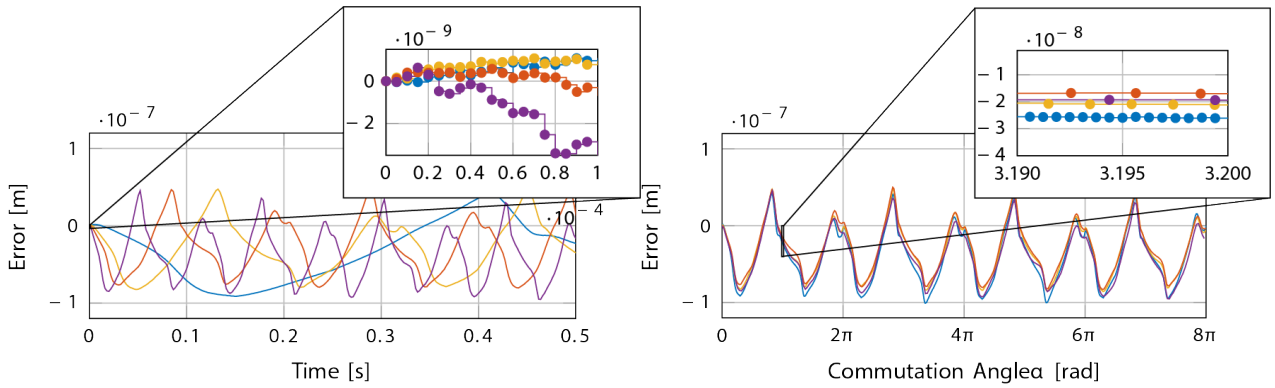

Figure 2 *Error in the time (left) and commutation-angle (right) domain. For varying velocities indicated by varying colours, the disturbances are non-periodic in the time domain but they are periodic in the commutation-angle domain.*

Approach: commutation-angle domain iterative learning control [1]

The main idea is to adapt the periodic waveforms to compensate the disturbances that are periodic in the commutation-angle domain. These waveforms define the inputs to the piezo elements as a function of the commutation angle, see Figure 1. The key challenge, as shown in Figure 2, is that the sampling is periodic in the time domain, and as a result, it is non-periodic in the iteration domain. To deal with this non-periodic sampling, the measured error is mapped to a set of continuous basis functions. This reconstruction of the continuous error signal is used to update the input u, shown in Figure 3. The input u is then used to update the waveforms for the shear elements of the piezo stepper, s_1 and s_2. This process is repeated iteratively until the disturbance is compensated. An example of the resulting compensating waveforms is shown in Figure 4.

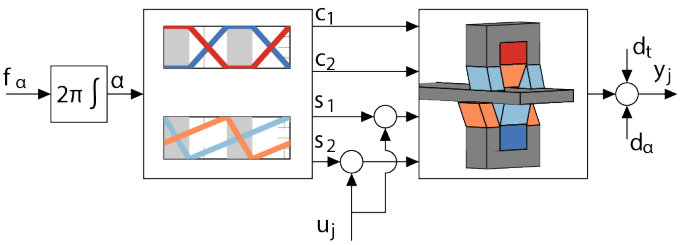

Figure 3 *Open-loop implementation of the enhanced waveforms for the piezo stepper.*

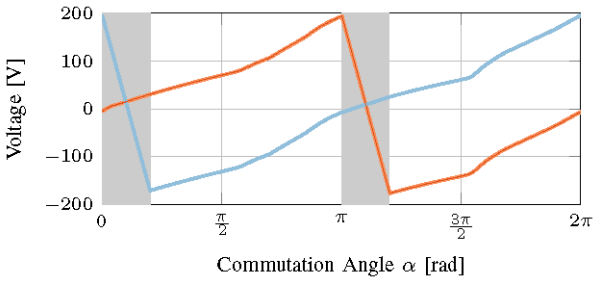

Figure 4 *Example of disturbance-compensating shear waveforms.*

Experimental results

Commutation-angle domain iterative learning control is applied to a piezo stepper actuator in experiments. The error and input signal are constructed using sinusoidal basis functions. Figure 5 shows that the RMS value of the error decreases significantly, and the corresponding error signals are shown in Figure 6. The remaining disturbances are non-periodic in the commutation-angle domain, will be addressed through a different compensation strategy.

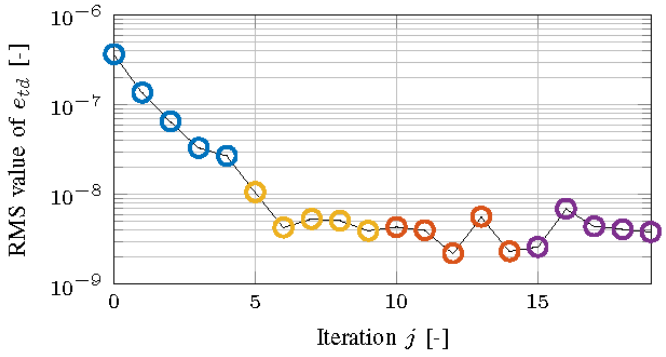

Figure 5 *Convergence of the RMS value of the detrended error for varying velocities.*

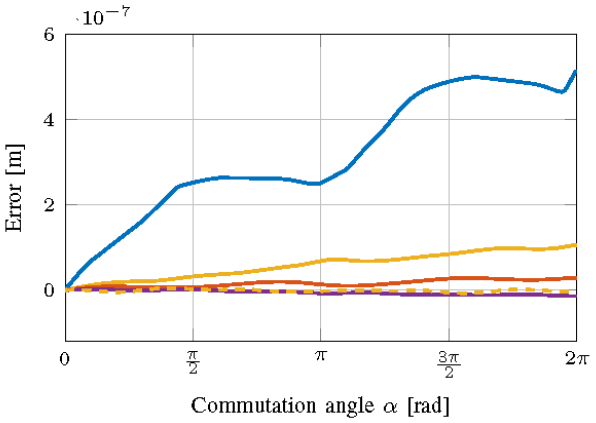

Figure 6 *Error signals for iterations **0**, **5**, **9**, **10** and **15**.*

Keywords: Piezo stepper actuators, iterative learning control, feedforward control

[1] Leontine Aarnoudse, Nard Strijbosch, Paul Tacx, Edwin Verschueren, Tom Oomen, 2023, "Compensating commutation-angle domain disturbances with application to waveform optimization for piezo stepper actuators", in: Mechatronics (to appear).