Lifted Frequency-Domain Identification of Closed-Loop Multirate Systems: Applied to Dual-Stage Actuator Hard Disk Drives

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Abstract: Frequency-domain representations are crucial for the design and performance evaluation of controllers in multirate systems, specifically to address intersample performance. The aim of this paperis to develop an effective frequency-domain system identification technique for closed-loop multirate systems using solely slow-rate output measurements. By indirect identification of multivariable time-invariant representations through lifting, in combination with local modeling techniques, the multirate system is effectively identified. The developed method is capable of accurate identification of closed-loop multirate systems within a single identification experiment, using fast-rate excitation and inputs, and slow-rate outputs. Finally, the developed framework is validated using a benchmark problem consisting of a multivariable dual-stage actuator from a hard disk drive, demonstrating its applicability and accuracy.

Keywords: Multirate, frequency response function, system identification, local parametric modeling, time-invariant representations, closed-loop identification.

1. BACKGROUND

Multirate sampling is becoming more common in mechatronics as increasing complexity results in multiple systems, sensors, and actuators with different sampling rates being interconnected, including sampled-data systems (Chen and Francis, 1995) and hard disk drives (Atsumi, 2023).

The development of FRF identification methods of multirate systems has been limited. In van Haren et al. (2025b) and this abstract, FRFs of multirate systems are effectively identified through synergistic use of time-invariant representations (Bittanti and Colaneri, 2009) and local modeling techniques (Pintelon and Schoukens, 2012). The method is capable of identifying multivariable systems beyond the Nyquist frequency of a slow-rate output, and is highly suitable for lightly-damped systems.

2. MOTIVATING APPLICATION

The problem in van Haren et al. (2025b) is directly motivated by a hard disk drive, such as the one shown in Figure 1, which exemplifies a closed-loop multirate system with slow-rate position measurements. The goal of the dual-stage actuator system is to minimize the tracking error of the magnetic head with respect to a track on the hard disk, as shown in Figure 1. The output is sampled at a slow-rate since the magnetic head position is determined based on a limited amount of sectors written on the disk.

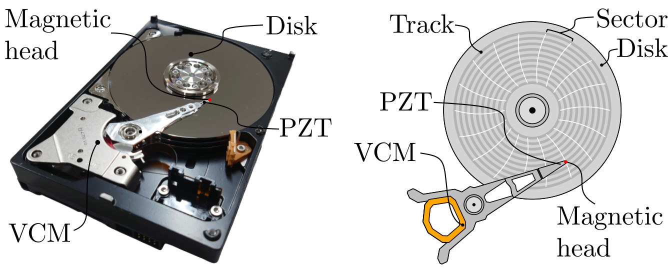

Fig. 1. (Left:) Photograph of hard disk drive. (Right:) Schematic overview of hard disk drive.

3. RESULTS

An identified FRF of the HDD is shown in Figure 2, which shows the developed method is capable of identifying the system accurately beyond the Nyquist frequency. The developed approach is crucial in control design of multirate systems, including multivariable and closed-loop systems with slow-rate outputs.

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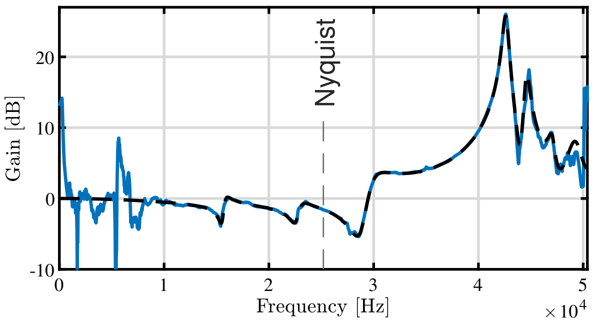

Fig. 2. The technique (—) identifies the FRF $P_p(\Omega_k)$ (- -) accurately, even beyond the Nyquist frequency (- -).

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