Open Invited Track: Reference Prefiltering for Precision Motion control

Tarunraj Singh * **Tomas Vyhlidal** **

* *University at Buffalo, Buffalo, NY 14260, USA (e-mail:tsingh@buffalo.edu).*
** *Czech Technical University in Prague, 160 00 - Prague 6, Czechia (e-mail: tomas.vyhlidal@fs.cvut.cz)*

Abstract: Input Shaping/Time-Delay Filtering is now an established approach for shaping reference inputs to minimize residual vibrations for rest-to-rest maneuvers, velocity tracking controllers, and to minimize excitation of high frequency unmodelled modes. At the core of successful reference shaping approaches have been the encapsulation of robustness to model parameter uncertainties. Special attention has also be paid to incorporation of the input shapers within closed loops of various configurations. This invited track will include latest contributions related to novel theoretical results and/or illustrations of applications of the reference shaping approaches for precision motion control.

Keywords: Input Shaping, Time-Delay Filters, Reference Shaping, Motion Control, Vibration Control, Path Planning of Underdamped Systems, Rest-to-Rest maneuvers.

Vibration mitigation of lightly damped structures including flexible arm robots, Atomic Force Microscopes (AFM), hard disk drives, cranes etc. has drawn attention over the past few decades. The demand for faster and lighter mechanisms in various applications has resulted in the design of underdamped structures whose motion induced vibrations need to be mitigated to realize the benefit of the lightweight structure. Building on the pioneering work of Otto Smith's Posicast control, Singer and Seering's concept of Input Shaping reignited the interest of the control community on the use of filtering to shape the reference input to a stable system. Over the past three decades, this renewed interest has resulted in a vast body of literature on precision motion control of vibratory systems. The contributions in the domain of reference shaping for precision motion control can be broadly classified into a six-part classification outlined further:

Robust design based on Nominal Models - In this approach, the sensitivity of the cost function to perturbations about the nominal model is minimized to generate robustness in the proximity of the nominal model. The ZVD Input Shaper falls into this category.

Worst case design based on interval uncertainties - When one has knowledge of the domain of uncertainty of the model parameters, an optimization problem which minimizes the worst performance results in a worst case design. One can also specify the maximum acceptable cost metric over the domain of uncertainty and design a prefilter to satisfy the constraint.

Chance constrained design based on probability distributions of uncertain parameters - To tradeoff between performance and robustness, a chance constraint problem formulation permits a risk based design. Here the designer specifies an acceptable probability that some system realizations will not achieve the desired performance, but of the ones that do, their performance is better than the worst cases design.

Design catering to structured and unstructured uncertainties - Here smoothness constraints are imposed on the shaped profile to minimize excitation of the unmodelled dynamics. These constraints can be imposed in conjunction with local sensitivity or worst case designs.

Optimal design of input shapers with delays of various distribution - In the input shaper design, various aspects such as robustness, time response and spectral features are to be handled simultaneously. Taking into account the structural requirements, the design task can be formulated as a standard constrained optimization task. Various shaper design methods by linear, quadradic or even nonlinear programming have been targeted. Next to the shaper with multiple lumped delays, input shapers with distributed delay have been addressed recently, bringing additional positive features such as i) signal filtration, and ii) positive spectral distribution features.

Feedback interconnections with input shapers - Next to reference shaping, input shapers proved applicable within feedback loops. The motivation is mainly in extending the capability to pre-compensate the flexible modes from reference responses to responses induced by disturbances. Already Smith has targeted this problem by inclusion of the shaper transfer function within a feedback compensator. However, it was in the past decade when the topic has undergone systematic development, leading to compensator-free implementations. This was possible thanks to development of i) distributed delay shapers with *retarded* spectral features, ii) tools for stabilization of arising infinite dimensional closed loop systems.