Zero dynamics, zero errors, zero compromise,

with application to medical X-ray systems

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Abstract

How to move a heavy load accurately and quickly? The load positioning performance for medical X-ray systems [1] is often dominated by zero dynamics. Zero dynamics (dynamics caused by plant zeros) become dominant in case of a high load mass and a limited drive-train stiffness.

Figure 1: Interventional X-ray system

Common feedforward design approaches (damping/mass/snap feedforward) are not able to address plant zeros. Moreover, inverse plant feedforward design approaches (rational filters/ILC) encounter severe issues with 1) Non-minimum phase zeros: unstable feedforward controllers, 2) Robustness: setpoint frequency content at plant zeros causing large feedforward oscillations.

A generic solution was presented in [2] which addresses all these issues: plant poles are covered by the feedforward filter, plant zeros are covered by the input shaping filter. Unfortunately, this approach is not applicable to an X-ray system. Due to plant dynamics at relatively low frequencies, actuator limitations are unacceptably violated.

A better solution has shown to be the introduction of a rational setpoint filter while sticking to common mass/damping feedforward control [3]: The system's center-of-mass follows the given setpoint while the rational setpoint filter addresses the residual dynamics as observed by the sensor. Both motor and load positioning performance improve by an order of magnitude without changing/slowing down the setpoint as is typically the case with e.g. J/A-tuning. Moreover, actuator limitations are not exceeded. Also, the setpoint filter can be easily tuned using FRF measurements. Finally, this approach is also applicable to other flexible motion systems, e.g. industrial robots.

[1] https://www.usa.philips.com/healthcare/e/image-guided-therapy

[2] D. Bruijnen and N. van Dijk, "Combined input shaping and feedforward control for flexible motion

systems," *2012 American Control Conference (ACC)*, Montreal, QC, 2012, pp. 2473-2478.

[3] Vibration reduction using advanced setpoint design, Philips Engineering Solutions