Modeling of Harmonic Control Arrays using MATLAB/Simulink with an Application to a Hot Rolling Mill Process

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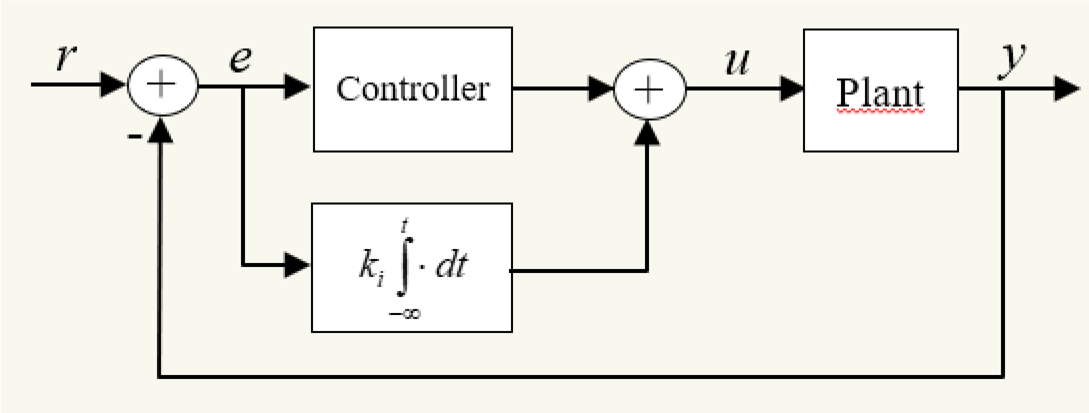
Murat Doğruel
İstanbul Sabahattin Zaim University
murat.dogruel@izu.edu.tr

Outline

- “Harmonic Control Arrays” method is introduced
- A MATLAB/Simulink modeling of HCAs is constructed
- An example is provided for demonstration
- A hot rolling mill process is considered
- The results are summarized

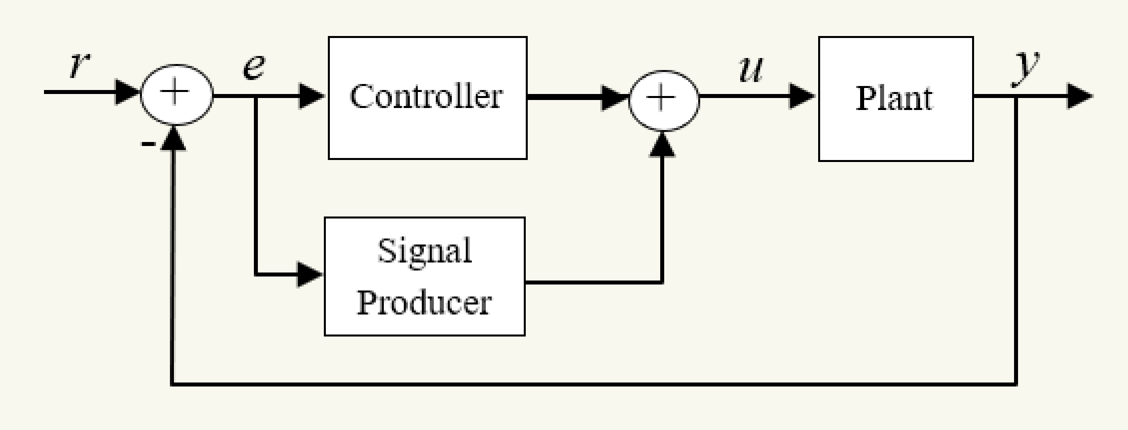
Motivation

For constant references, the steady state error can be automatically eliminated by simply utilizing an integral term in unitary feedback systems. This is frequently and very usefully employed in many industrial control solutions.

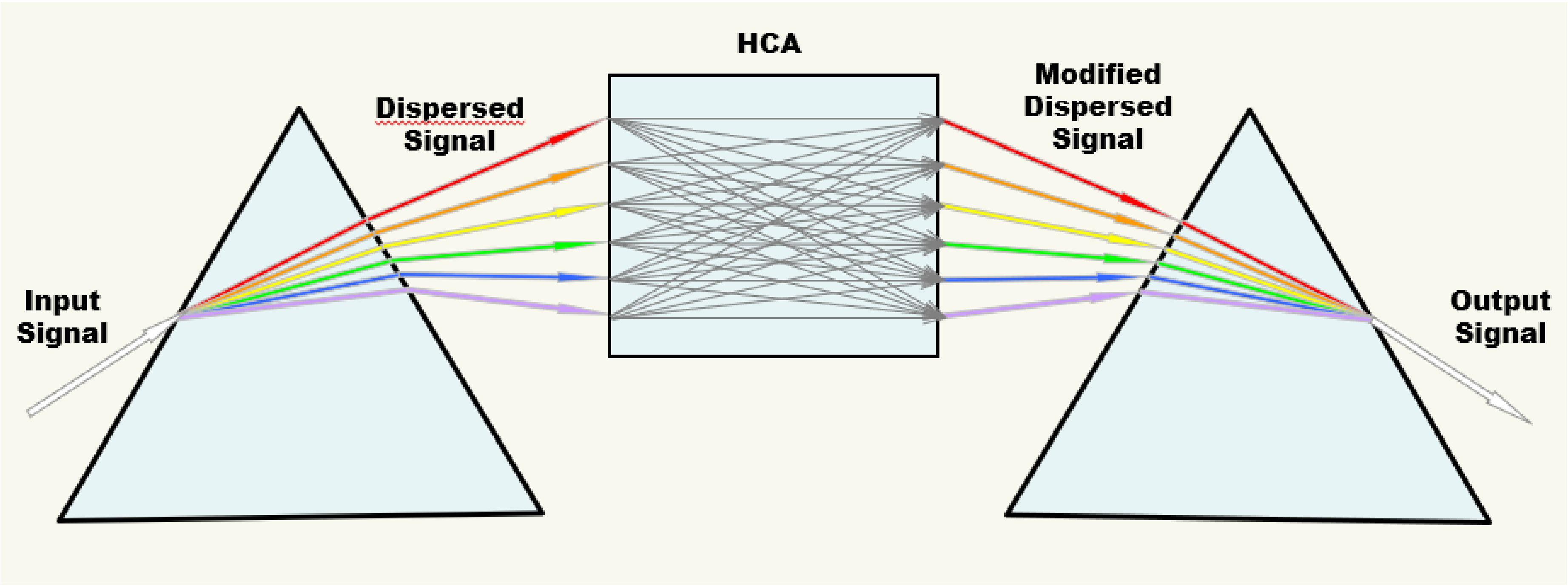


Motivation

How can we achieve the zero-error performance for systems containing periodic references and/or periodic disturbances?



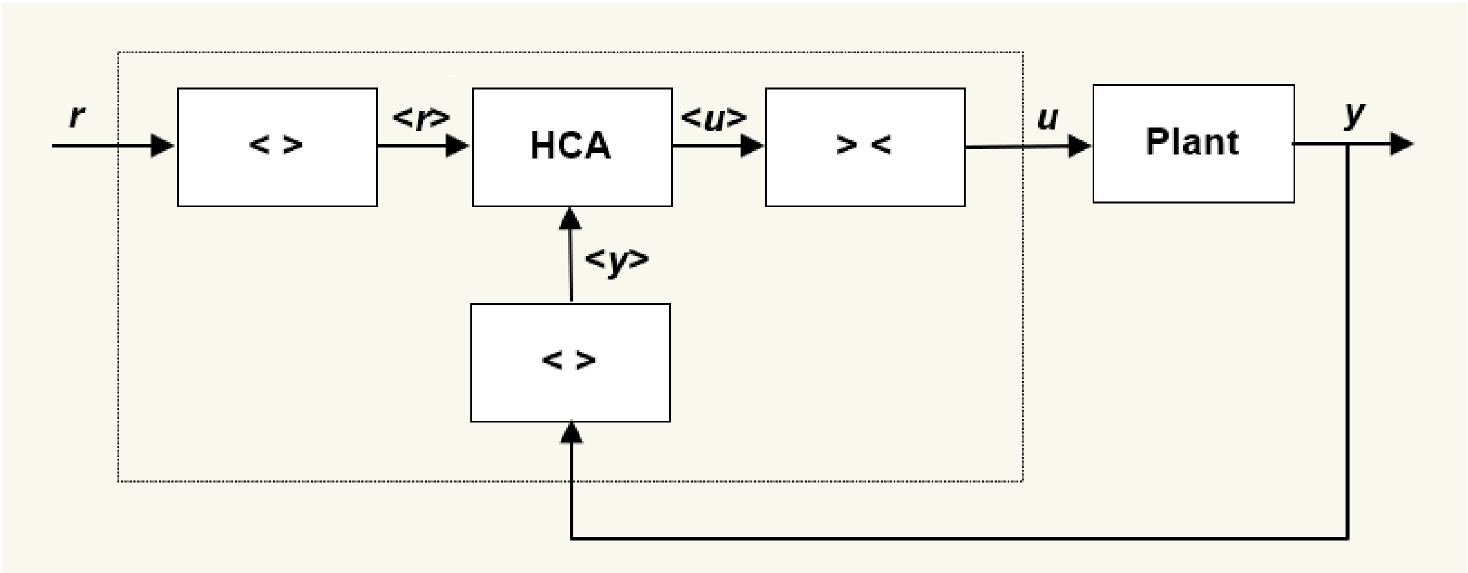
An Illustration of the HCA Idea



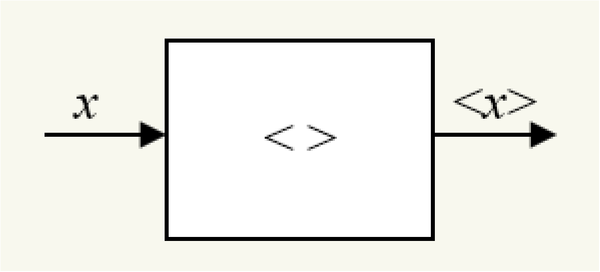
Each harmonic component is individually controlled to construct the output.

The HCA Method

The method is based on automatically constructing the appropriate control signal by adjusting the complex levels of its harmonic components, using the harmonic components of the reference and output signals.



Harmonic Disperser

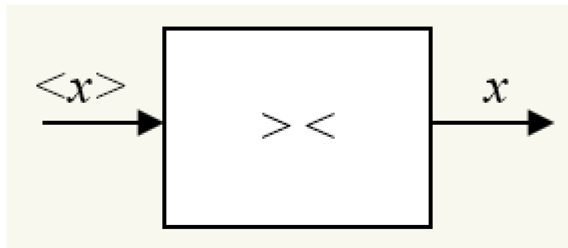


$$< x >_h (t) = \frac{1}{T} \int_{t-T}^{t} x(\tau) e^{-jh\omega\tau} d\tau$$

$$\omega = 2\pi / T$$

$$< x > = \begin{bmatrix} < x >_0 \\ < x >_1 \\ \vdots \\ < x >_H \end{bmatrix}$$

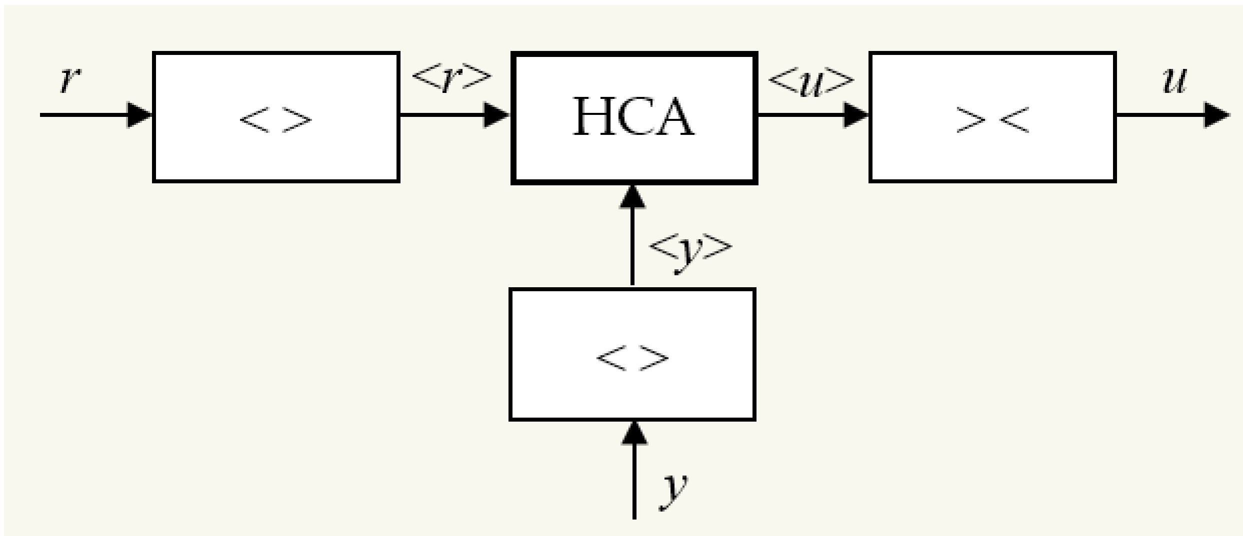
Harmonic Assembler



$$x(t) = \sum_{h=-H}^{H} < x >_h (t) e^{jh\omega t}$$

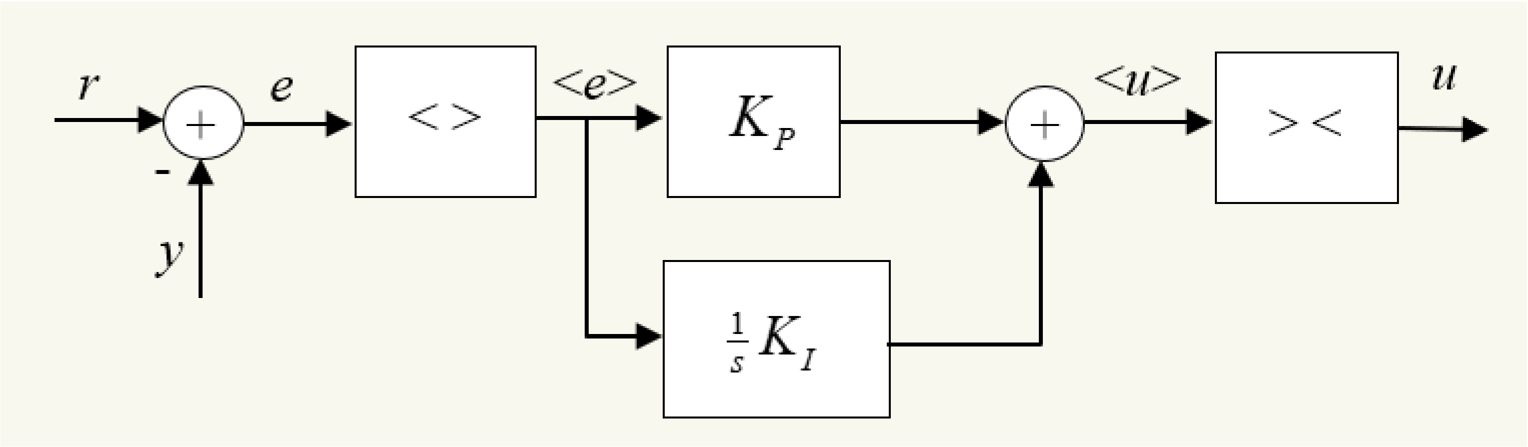
$$< x >_{-h} = \left(< x >_h \right)^*$$

Harmonic Control Arrays



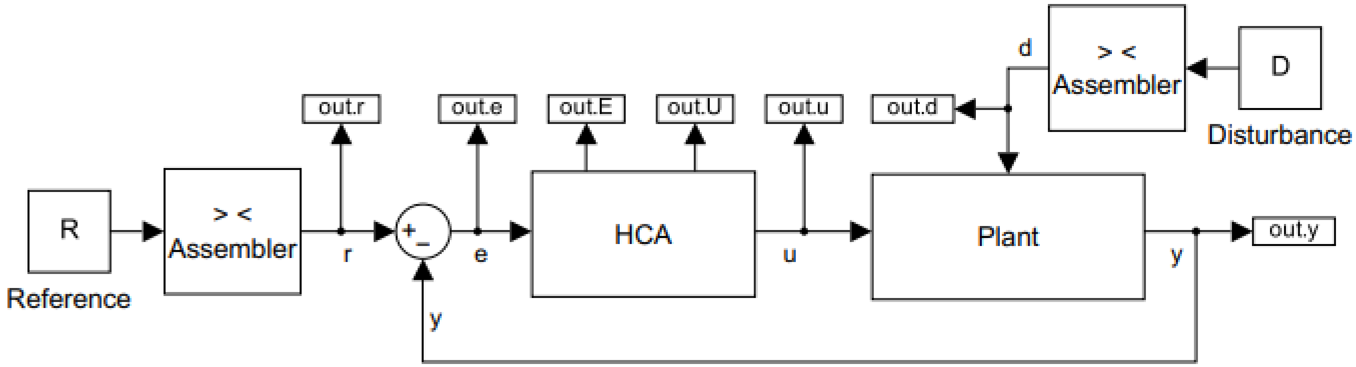
The HCA block tries to "optimally" construct $<u>$ using $<r>$ and $<y>$ (and their previous values).

Harmonic PI Control Array

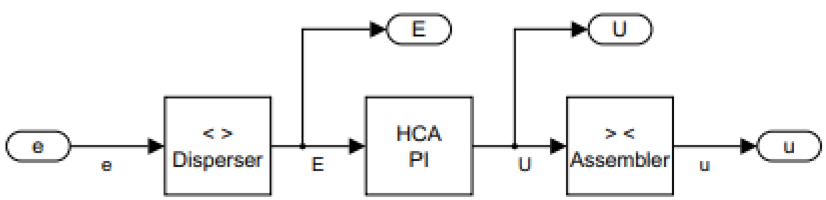


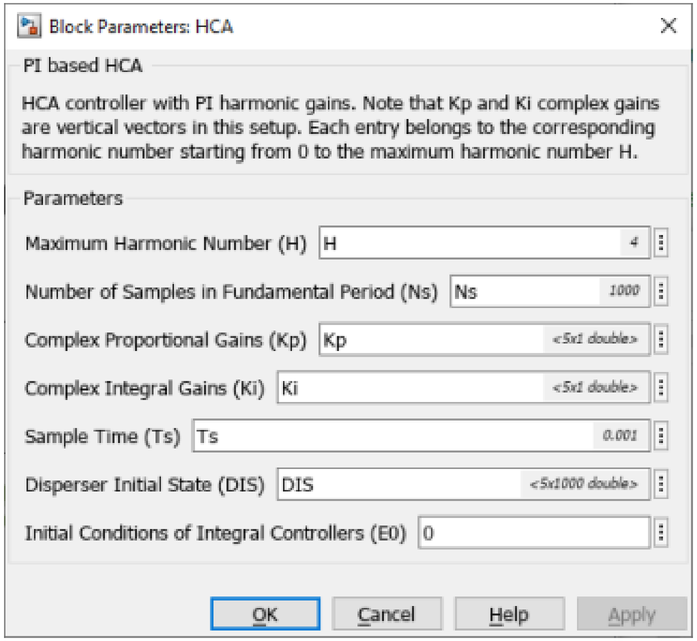
$$< u > = K_P < e > + K_I \int_{-\infty}^{t} < e > dt$$

Blocks in the HCA structure



Discrete-Time HCA Controlled Unitary Feedback System





Construction of a Simulink Model

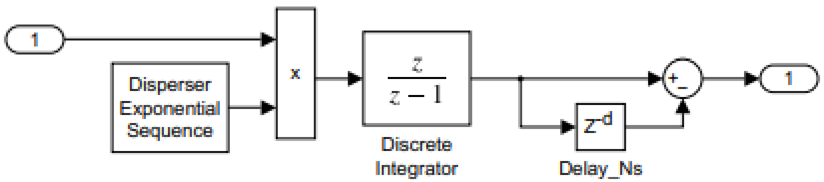


Fig. 4. Construction of the disperser.

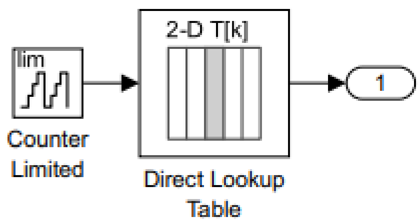


Fig. 5. Construction of the exponential sequence generator.

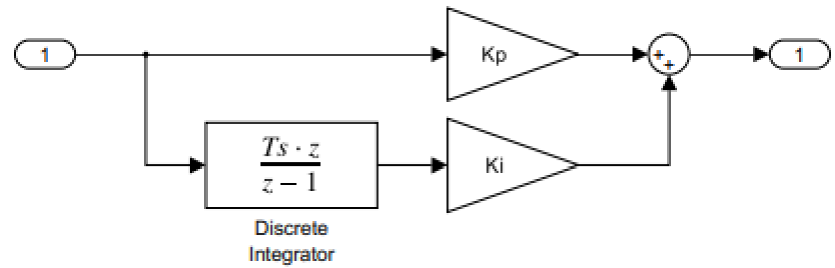


Fig. 6. Construction of the HCA PI controller.

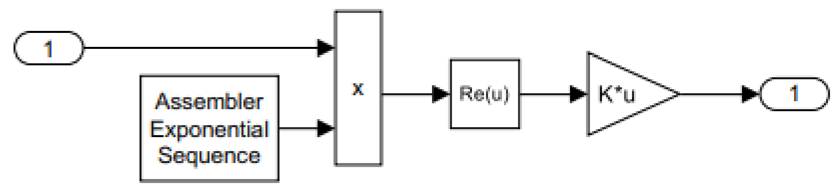


Fig. 7. Construction of the assembler.

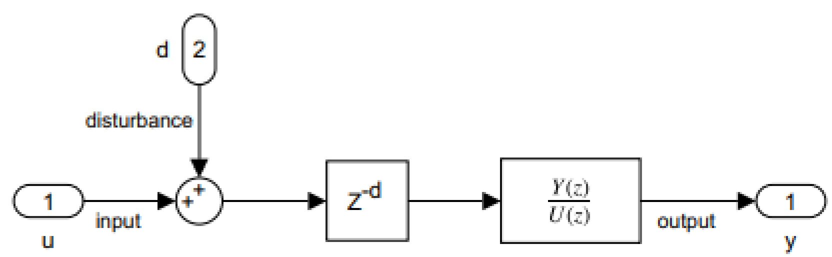


Fig. 8. A typical LTI plant model.

A Test System

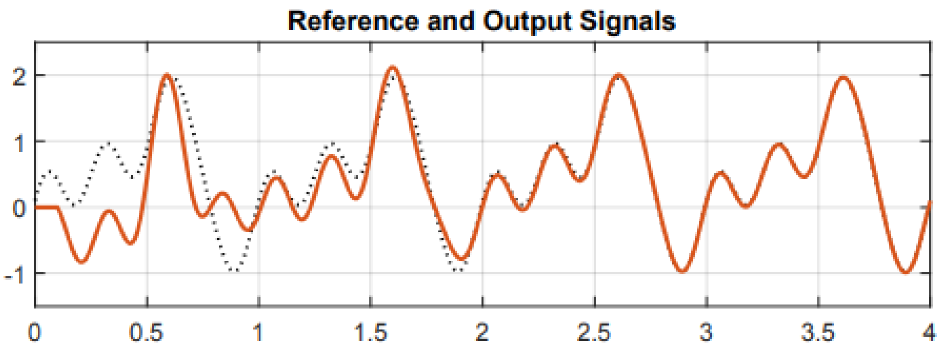
$$G(s) = \frac{10}{s+10} e^{-0.1s}$$

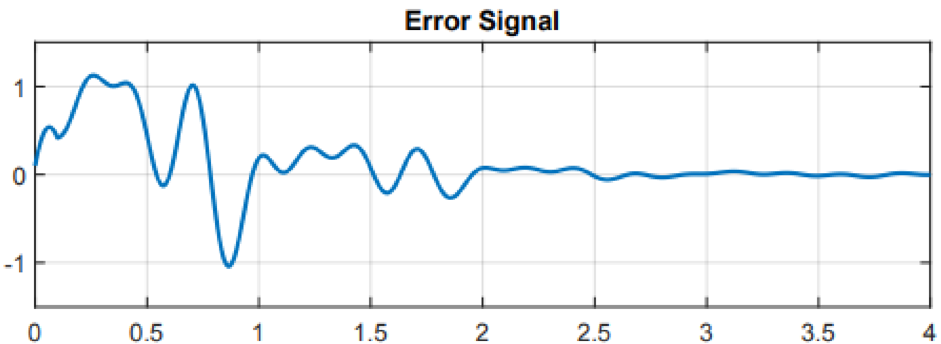
H = 4

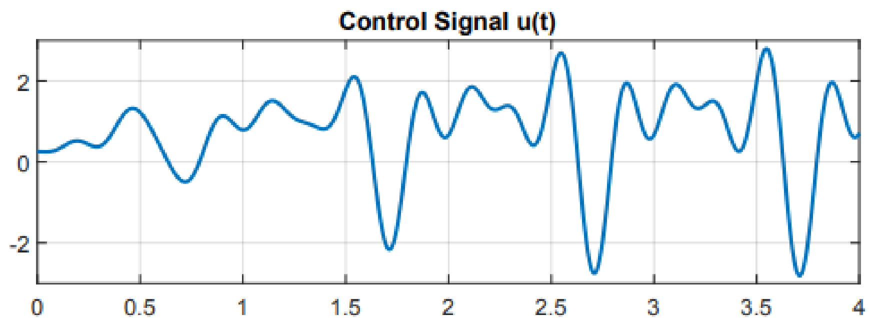
R=[0.5; -0.4; -0.3j; 0.2; -0.1j]

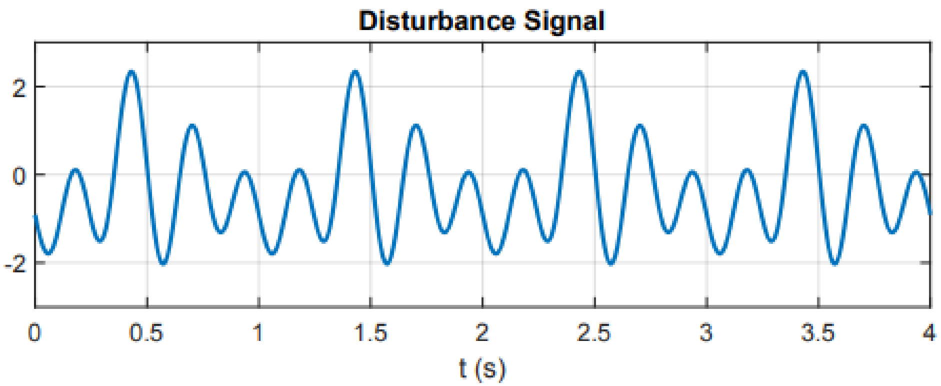
D=[-0.35; -0.28; 0.22j; -0.33j; 0.61j]

$$K_P = \begin{bmatrix} 0.5 & 0 & 0 & 0 & 0 \end{bmatrix}^T,$$
$$K_I = \begin{bmatrix} 1.2 & 0.8e^{1.2j} & 1.1e^{2.2j} & 1.5e^{3j} & 2.1e^{-2.6j} \end{bmatrix}^T.$$









Control of a Hot Rolling Mill Process

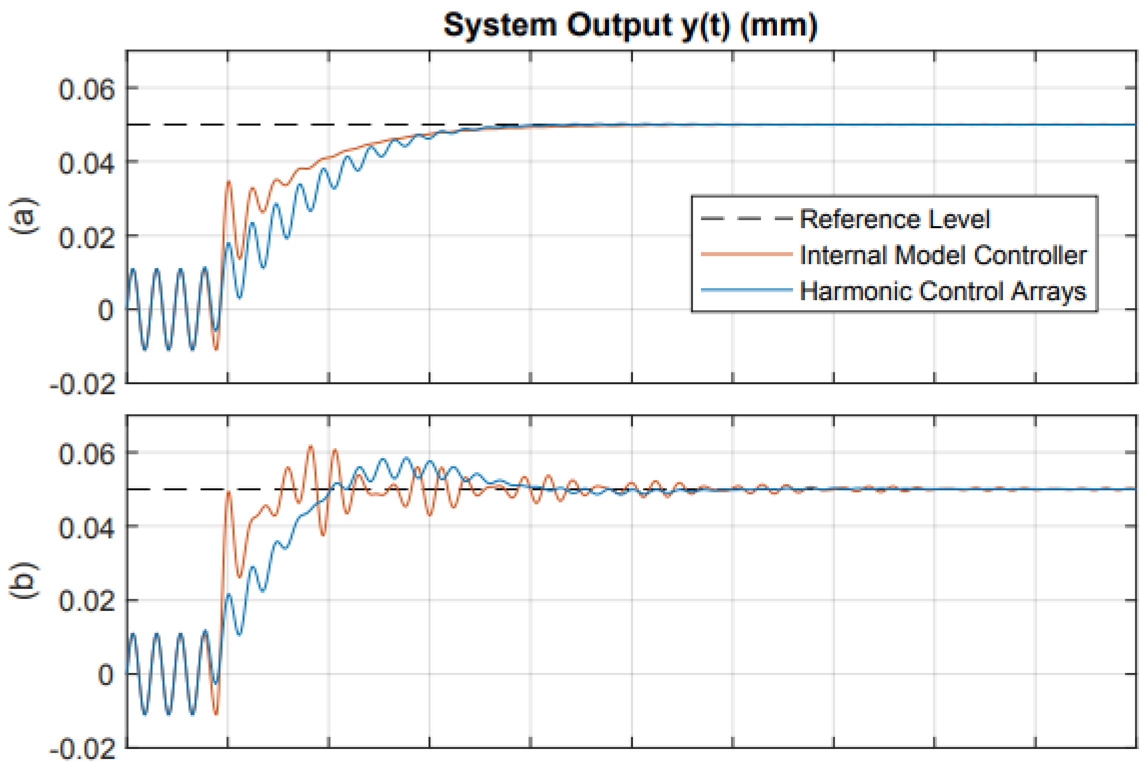
[12] Can Kutlu Yuksel, Jaroslav Busek, Silviu-Iulian Niculescu, Tomas Vyhlidal, "Internal Model Controller to Attenuate Periodic Disturbance of a First-Order Time-Delay System", 2021 European Control Conference (ECC), pp. 81-86, 2021.

$$G_{id}(s) = \frac{K}{Ts+1}e^{-s\tau}$$

$$d(t) = 0.011\sin(5.32t)(mm)$$

An IMC controller with a third-order filter is proposed

$$C_d(s) = \frac{14.28s^2 + 29.75s + 14.88}{s^3 + 1.92s^2 + 30.17s + 7.44}e^{-0.634s}$$



T = Tm = 0.8s
K = Km = 0.5

T = 0.64s
K = 0.7

$T = 1.18s \quad D = [0 \quad -0.0055j]^T \quad R = [0.05 \quad 0]^T \quad H = 1$

$K_p = [0.28 \quad -0.4+0.45j]^T \quad K_i = [0.22 \quad -0.9+0.43j]^T$

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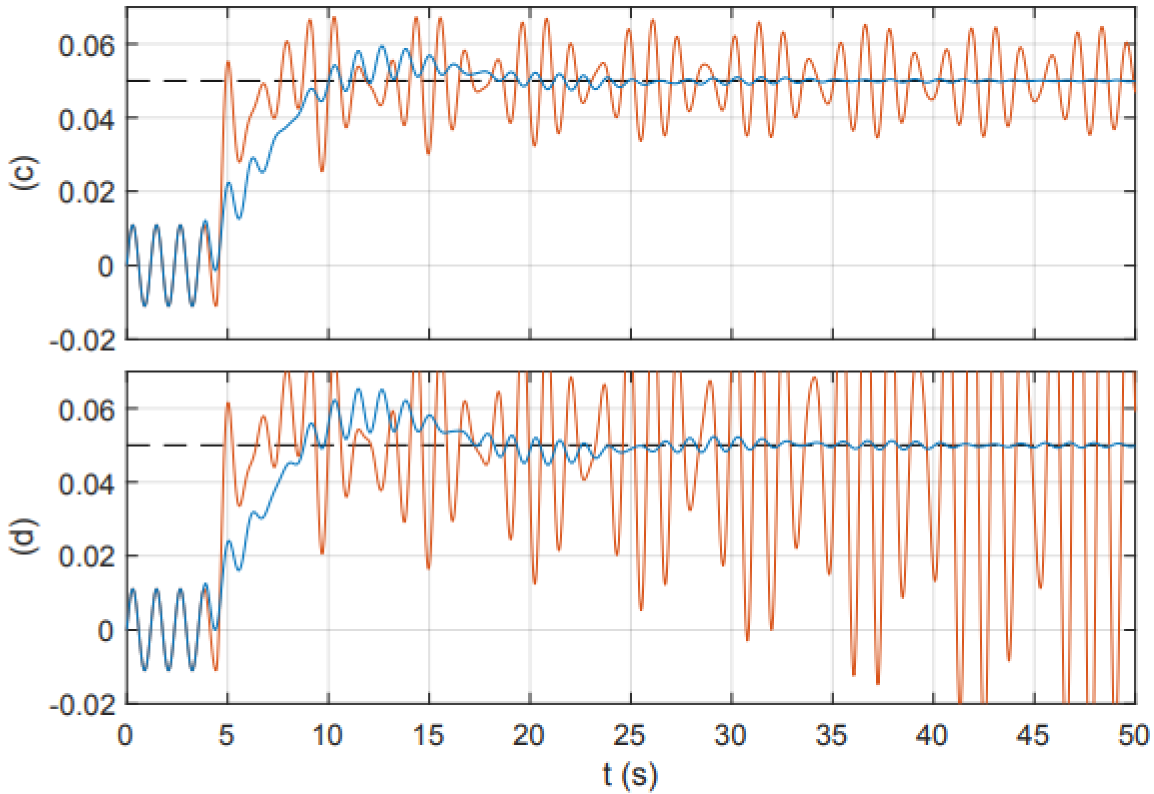

T = 0.5s
K = 0.7

T = 0.5s
K = 0.8

Conclusions

- Harmonic Control Array method is presented with some examples.
- A MATLAB/Simulink modeling of HCAs is constructed using the current model library.
- A hot rolling mill process example in the literature is considered.
- It is shown that the HCA performance is more robust than the internal model controller in this case.
- Harmonic control arrays could be a relatively simple but effective control strategy for periodic reference tracking, eliminating periodic disturbances, vibration suppression, noise cancellation, industrial electronics, power converters and motor drives.

Thank You. Any Questions?