# Synchronized Motion Control for Overall Performance Enhancement: A Youla Framework Applied to a Wafer Scanner

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## 1 Background

Many machines used in the manufacturing industry consist of multiple subsystems. In view of complexity, the design and control of these systems of systems is often divided into manageable subproblems. Due to the decentralized control [1] approach of these systems their full system performance is often sub-optimal. The main idea of this work is to provide a framework that can be used to design coupling elements for the decentralized control architecture in order to improve overall performance.

## 2 Problem

An example of a system of systems is a waferscanner used in the lithographic industry. Typically, both sub-systems can be considered approximately decoupled. Thus, in the scan direction, the combined system can be modeled as two decentralized scalar control loops as shown in Fig. 1. Accuracy during die exposure depends on the relative error, $e_{wr} = y_w - y_r$, between the two motion stages. Therefore,

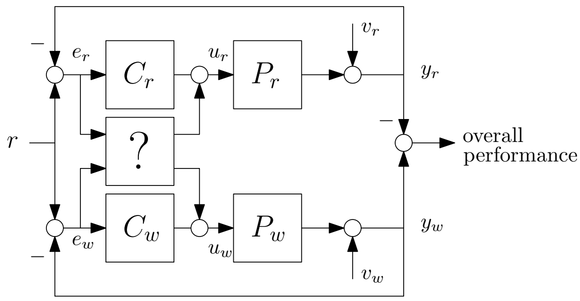


Figure 1: This work aims to add coupling filters between the two decentralized loops to improve the overall performance.

minimization of the two individual tracking errors $e_r$ and $e_w$ is a sufficient condition for a small relative error. However, the full system performance is limited by the performance limitations of each individual subsystem. In this work, the main goal is to design an add-on control element that retains the existing diagonal control elements and minimizes the relative error.

## 3 Approach

The coupling problem is recast as a Youla parameterization using coprime factorization, shown in Fig. 2. The Youla parameterization allows for a systematic analysis and separation of the nominal controller $K_0 = N_k D_k^{-1}$ and nominal

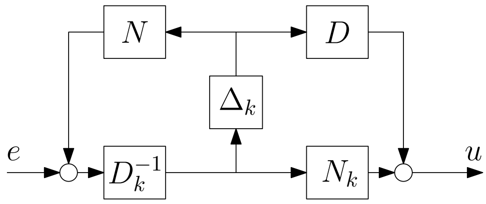


Figure 2: Controller diagram of a Youla parameterization using coprime factorization. Here, all blocks are $(2 \times 2)$ transfer function matrices.

plant $P_0 = ND^{-1}$ and the additional add-on controller freedom $\Delta_k$. Furthermore, the framework is extended to include plant uncertainty to provide a robust stability proof [2].

## 4 Result

The Youla framework, together with design guidelines, allows for a straightforward design of the coupling elements in $\Delta_k$ while guaranteeing nominal system stability. The full system performance, shown in Fig. 3, is improved beyond the limitations of the individual sub-systems by the addition of the coupling elements to the decentralized loops. Using this approach the decentralized controllers are unchanged and invariant to the additional coupling which facilitates industrial adaptation.

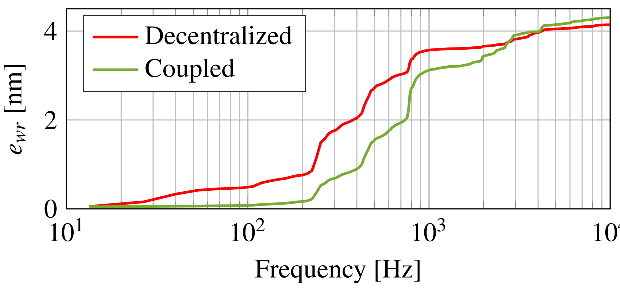


Figure 3: Cumulative relative servo error $e_{wr}$ during a typical exposure scan. Low-frequency reduction, most critical to overlay performance, is achieved.

## References

[1] T.-T. Tay, I. Mareels, and J. B. Moore, High performance control. Springer Science & Business Media, 2012.

[2] Schrama, R., Bongers, P., and Bosgra, O. (1992). Robust stability under simultaneous perturbations of linear plant and controller. In Proceedings of the 31st Conference on Decision and Control., 2137-2139. IEEE, Tucson, Arizona.