Minimal-norm globally non - overshooting/undershooting control of linear multivariable systems

A THESIS

submitted by

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\I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then nding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

- Isaac Newton

Declaration

I hereby declare that the entire work embodied in this thesis results from the investigations carried out by me in the **School of Computing and Electrical Engineering, Indian Institute of Technology Mandi**, under **Dr. Tushar Jain's** supervision. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on other investigators' nding.

Abhishek Dhyani

Place: Mandi **Abhishek Dhyani**

Date: 25th February 2022

Thesis Certi cate

This is to certify that the thesis entitled **Minimal-norm globally non- overshooting/ undershooting control of linear multivariable systems"**, submitted by **Abhishek Dhyani**, to the Indian Institute of Technology Mandi for the award of the Degree of Master of Science (by research) is a bona de record of research work carried out by him under my supervision. The content of this thesis, in full or in parts, have not been submitted to any other institute or university for the award of any degree or diploma.

Place: Mandi

Dr. Tushar Jain

Date: 25th February 2022

(Guide)

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Abstract

One of the key objectives to consider while designing closed-loop control systems is that the plant output should follow the pre-speci ed reference signal or the setpoint without any overshoots or undershoots. Accordingly, the literature encompassing the broad area of control theory has extensively addressed the transient response improvement and tracking control problems of linear time-invariant (LTI) systems. Several design techniques exist in the literature for the transient response shaping of single-input/output (SISO) LTI systems utilising state-feedback controllers. While the state-feedback controller design methods for SISO systems can be suitably utilised for multi-input/output (MIMO) systems to non-uniquely place the eigenvalues at the desired locations, eigenvalue assignment alone may not achieve the desired transient performance for MIMO systems due to the coupling between the input and output variables.

For several \positioning" control problems such as the control of elevators, hard disk read/write head control, coordination of multiagent systems, etc., achieving the non - overshooting/ undershooting (NOUS) tracking control objectives in the output response of the closed-loop system are crucial. These objectives simultaneously target both the steady-state and transient performance speci cations and are achieved by assigning the complete eigenstructure (eigenvalues and eigenvectors) of the resulting closed-loop system. The \globally" NOUS (GNOUS) control problem refers to obtaining the response from a state-feedback control system to a constant step reference signal such that the resulting system yields a monotonic response, independently of the initial conditions and step reference magnitudes. In addition, one of the desired prerequisites of an industrial plant is to have a minimum operation and maintenance cost, which can be achieved by installing low-cost actuators. Mathematically, this translates to guaranteeing the desired control performance with the minimal control e orts, or equivalently, synthesizing the state-feedback controller of the minimal Frobenius norm. The above two control objectives, namely, GNOUS tracking and minimal norm of the state-feedback gain matrix, are widely addressed in the literature. Since these control objectives are con icting because they are inversely proportional to each other, particularly for the case of scalar input LTI systems, they have been addressed separately even for multiple input LTI systems. Through this work, the open problem of simultaneously achieving these set of objectives for multivariable LTI systems is formulated and extensively addressed.

Firstly, new results for the GNOUS tracking control problem for MIMO LTI systems are presented, incorporating the practically relevant control objective of a minimal-norm feedback gain matrix. Further, an algorithm is presented to synthesise a minimal-norm state-feedback controller such that the GNOUS tracking control objectives are achieved in all the output responses of the closed-loop system with the desired rate of convergence. The key idea behind this algorithm is to utilise the additional degree of freedom of multivariable systems for placing the eigenvalues of the closed-loop system within a pre-specified region in the complex plane. An upper bound on the worst-case convergence rate in all output responses for a pre-specified disk region is also provided.

Subsequently, the proposed algorithm is extended to the class of decoupled large-scale MIMO LTI systems. These systems feature a high-dimensional plant model and are composed of a number of independent subsystems. Multi-area power systems, gas distribution networks, and ecological systems are all examples. Finally, this work demonstrates some numerical and experimental results to validate the effectiveness of the proposed algorithms.

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