Robust Fractional Order LQI Controller Design for Quadruple Tank Process and its Feasibility Study in Bond Graph Domain - An Optimisation Approach

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by

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Abstract

The Quadruple Tank Process (QTP) is a classical control problem often used in control theory and practical research. This process is a valuable testbed for studying and implementing control algorithms, allowing researchers/engineers to explore the various design process such as feedback control in the presence of uncertainties and optimisation in a practical context. The main objective of the problem is to maintain the desired levels in the bottom two tanks under (i) nonlinearity due to the interconnected dynamics (ii) potential coupling between the tanks and (iii) disturbance and uncertainty conditions. Interestingly, QTP exhibits its operation under both minimum and non-minimum phase modes. In specific, designing a controller for a non-minimum phase system requires more attention due to its inherent complexities and challenges involved.

The Linear Quadratic Integrator (LQI) controller, a widely acclaimed control design technique combines both feedback control i.e Linear Quadratic Regulator (LQR) and feedforward integral control strategy. The integral action of the LQI controller plays an important role in the system's performance by integrating the error signal between the actual and desired states over time, hence it eliminates the steady state error which drives the system towards the desired setpoint. The optimisation problem leads to minimise the cost function that combines quadratic penalties on state deviations, input deviations and integrated error signals along with constraints on control inputs and states.

The initial phase of the research work proposes robust Fractional Order LQI (FOLQI) controller design for QTP in the presence of disturbance and uncertainty conditions. This approach involves utilising fractional calculus concepts in designing the controller which allows more flexibility and adaptability in handling complex dynamics. By incorporating fractionality in the integrator part of the LQI controller, the FOLQI controller can capture more intricate system behaviours and effectively improve the system performance. The controller parameters of FOLQI is obtained by minimising control effort in the presence of load disturbance conditions along with time domain constraints such as overshoot, settling time and steady state error.

The optimal tuning of FOLQI controller parameters are obtained by solving the proposed constrained optimisation problem using (i) deterministic approach and (ii) heuristic approach. Deterministic optimisation methods aim to find the optimal solution by systematically exploring the entire solution space or using mathematical algorithms to determine

the best solution. These methods guarantee convergence to the global optimum (if such a solution exists) under certain conditions. It utilises the fmincon function from MATLAB which uses the Sequential Quadratic Programming (SQP) algorithm as a solver. The superior time response characteristics obtained from FOLQI controller are compared with responses obtained from the existing Integer Order LQI (IOLQI) and Linear Active Disturbance Rejection (LADR) controllers.

To enhance the performance, heuristic optimisation methods such as Cuckoo Search (CS), Accelerated Particle Swarm Optimisation (APSO) and FireFly (FF) are used to solve the proposed constrained optimisation problem. These methods are beneficial for complex problems where deterministic optimisation techniques may need more computational complexity or ample solution space that provides the solution within a reasonable time frame. The superior performance of these algorithms are shown by conducting simulations in the presence of disturbance along with parameter uncertainty conditions and the results are compared with the existing IOLQI controller.

In the second phase of the research work, the Bond Graph (BG) based QTP model along with FOLQI controller is proposed. BG serve as a graphical modelling technique, offering a unified framework for representing the dynamics of interconnected physical systems. The closed loop configuration of the QTP and FOLQI controller are modelled using BG technique. A unconstrained optimisation problem is proposed to tune the FOLQI controller parameters using various optimisation algorithms such as Newton Raphson, Davidon–Fletcher–Powell, Steepest Descent Method and Broyden–Fletcher–Goldfarb–Shanno. The obtained results using FOLQI controller are compared with the existing IOLQI controller.