

COMPARATIVE ANALYSIS OF OPTIMAL AND FUZZY LOGIC
CONTROLLERS FOR NONLINEAR TECHNOLOGICAL
PROCESSES

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Abstract: *This paper proposes a methodological framework for the comparative evaluation of the dynamic performance of optimal and fuzzy logic controllers applied to nonlinear technological processes. An automatic yarn tension control system used in the warping process is selected as the case study. Variations in the process parameters and external disturbances are considered. A linear quadratic regulator (LQR), designed on the basis of a linearized mathematical model, is compared with a Mamdani-type fuzzy logic controller governed by a set of linguistic rules. The evaluation criteria include settling time, overshoot, root mean square error (RMSE), integral of absolute error (IAE), and sensitivity to parameter variations. The present study establishes the evaluation methodology; conclusions regarding the quantitative superiority of either controller require subsequent simulation and validation.*

Keywords: *nonlinear system, linear quadratic regulator (LQR), fuzzy logic, yarn tension, warping process, parametric uncertainty.*

1. Introduction

Effective control of nonlinear technological processes remains a challenging problem in modern industrial production owing to parametric uncertainty, external disturbances, and time-varying plant dynamics. Under these conditions, optimal and intelligent control algorithms are of particular importance for maintaining control accuracy and system stability [1].

The linear quadratic regulator (LQR) is designed by minimizing a quadratic performance index. However, because its synthesis relies on a linearized mathematical model, its performance may deteriorate in the presence of pronounced nonlinearities and parameter variations [2]. By contrast, fuzzy logic controllers can represent nonlinear relationships through linguistic rules and membership functions [3]. This study examines these two control approaches in the context of yarn tension regulation during textile warping. Changes in package diameter, yarn elasticity, and frictional forces influence the control performance. Accordingly, a comparative assessment under identical operating conditions and using a common mathematical model is necessary [4].

The objective of this study is to compare the dynamic performance of an optimal LQR controller and a fuzzy logic controller in MATLAB/Simulink, with particular emphasis on settling time, overshoot, control error, and sensitivity to parametric uncertainty.

2. Research Methodology

Yarn tension $T(t)$ is considered the controlled variable, whereas $u(t)$ denotes the control input applied to the electric drive. The dynamics of the technological process can be represented in general form as follows:

$$\begin{aligned}\dot{x}(t) &= f(x(t), u(t), d(t), p(t), \\ T(t) &= h(x(t)).\end{aligned}\tag{1}$$

where $\dot{x}(t)$ – is the state vector, $d(t)$ – denotes the disturbance input, and $p(t)$ – represents the varying parameters. The model linearized about a selected operating point is written as:

$$\Delta\dot{x}(t) = A\Delta x(t) + \Delta u(t)\tag{2}$$

The LQR controller is synthesized by minimizing a quadratic performance functional $J = \int_0^\infty [\Delta x^T(t)Q\Delta x(t) + \Delta u^T(t)R\Delta u(t)]dt$, yielding an optimal state-feedback control law $\Delta u = -K\Delta x$. Here, P denotes the stabilizing solution of the algebraic Riccati equation $K = R^{-1}B^TP$. An integral action or

feedforward compensation may be incorporated, if required, to enable reference tracking.

For the fuzzy logic controller, two input variables $e(t) = T_{ref}(t) - T(t)$ and $\dot{e}(t) = \frac{de(t)}{dt}$ are selected. Using the linguistic terms Negative (N), Zero (Z), and Positive (P), a rule base comprising $3 \times 3 = 9$ fuzzy rules is constructed. The control signal is generated through $u_F(t) = F(e(t), \dot{e}(t))$ Mamdani inference and defuzzification.

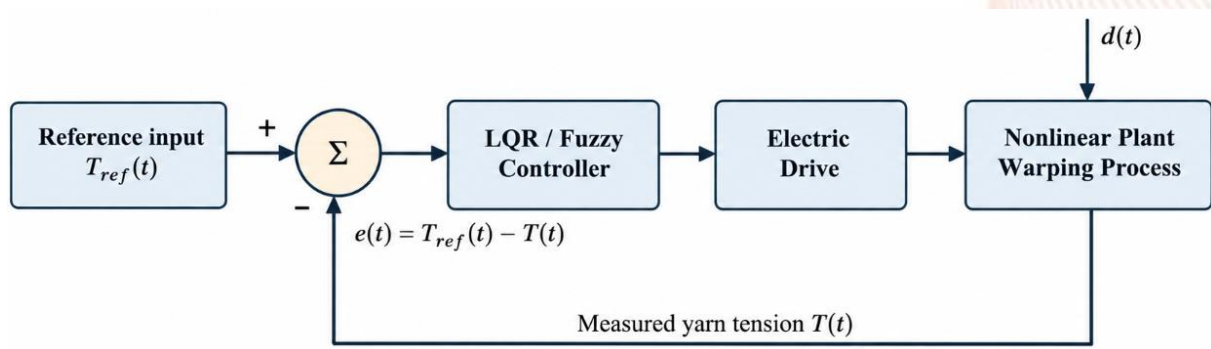


Figure 1. General closed-loop control architecture for the comparative evaluation of LQR and fuzzy logic controllers.

During simulation, the controllers are connected to the same plant separately rather than simultaneously. The evaluation scenarios comprise nominal parameters, a 25% and a 50% increase in the time constant, and the presence of an external disturbance. The quantitative evaluation criteria include [expressions missing in the source document], together with settling time and overshoot.

3. Results and Discussion

To ensure a meaningful comparison, both algorithms must be evaluated using identical initial conditions, input signals, and parameter variations. The following plot does not represent experimental data or outputs obtained from implemented LQR and fuzzy controller models. Rather, it is a conceptual

illustration of how their transient responses may be compared

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N e_i^2} \text{ and } IAE = \int_0^{t_f} |e(t)| dt \text{ presented.}$$

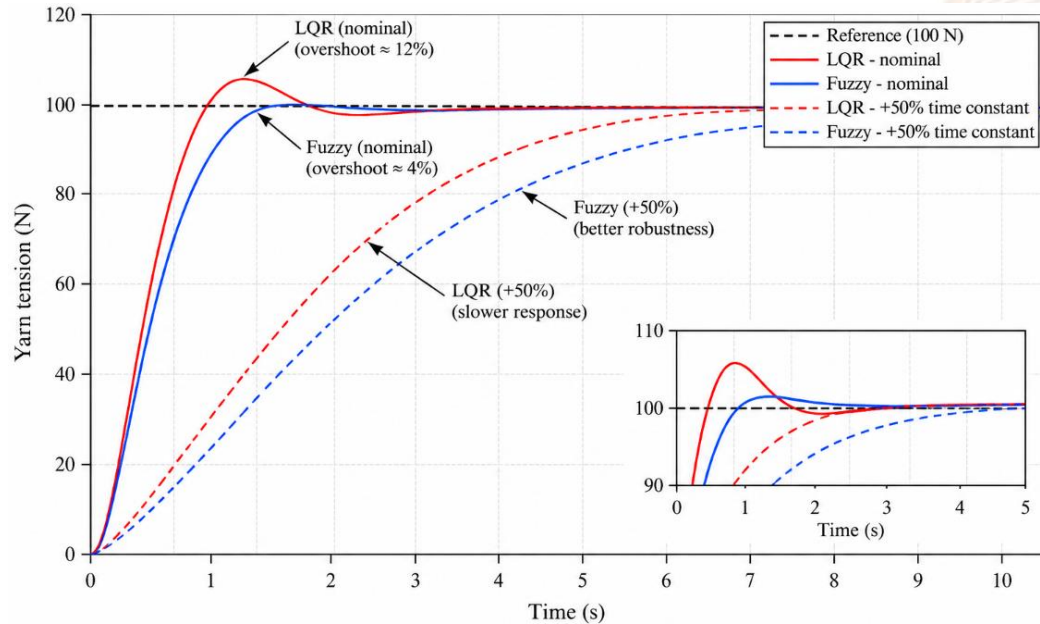


Figure 2. Illustrative comparison of LQR and fuzzy controller transient responses (not actual simulation results).

Table 1. Criteria for Comparative Evaluation of LQR and Fuzzy Logic Controller Performance Under Different Operating Conditions.

Test condition	LQR evaluation	Fuzzy logic evaluation
Nominal parameters	Baseline performance metrics	Baseline performance metrics
Time constant +25%	Parametric sensitivity	Parametric sensitivity
Time constant +50%	Dynamic performance	Dynamic performance
External disturbance	Control error and recovery time	Control error and recovery time

From a theoretical perspective, the LQR minimizes a precisely defined performance criterion for the nominal linearized model. Depending on the design of its rule base, a fuzzy logic controller may exhibit nonlinear control behavior across different operating regimes. Nevertheless, the practical superiority of either approach can only be established using an identified plant

model, explicitly specified tuning parameters, and quantitatively evaluated performance indicators.

4. Conclusion

A unified methodological framework has been developed for comparing LQR and fuzzy logic controllers applied to nonlinear technological processes. The control architecture, mathematical evaluation criteria, and parametric uncertainty scenarios have been defined. To establish scientifically substantiated comparative findings, the proposed architectures must be implemented in MATLAB/Simulink, their actual transient responses must be obtained, and the corresponding performance indicators must be reported quantitatively in a comparative table. At the present stage, the principal limitation is the absence of identified plant parameters and validated quantitative performance results.

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