COMPARISON OF SOME OPTIMIZATION TECHNIQUES IN ROBUST PROCESS CONTROL DESIGN

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CERTIFICATION

We certify that this research programme was supervised by us and approved in accordance with requirements for the award of Master of Science (M.Sc.) Degree in Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

....	....
Prof. O. Taiwo	Dr. (Mrs) E. F Aransiola
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ABSTRACT

The research explored standard ways of quantifying uncertainties in systems and assessing controller performance in the frequency domain; examined four robust process control design strategies implementing them on typical multivariable systems. This was with the view of delineating their advantages and disadvantages.

The mathematical models of selected multivariable systems were obtained from the literature. Different sources of uncertainties were identified for each system. Nominal models were arrived at by considering the average plant using the Nyquist plots of different operating points in some instances, while the model of the nominal operating point in some other instances were chosen. In the previous case, the frequency plots of deviations of the different operating points from the nominal model were used to model the uncertainty weights whereas in the latter instance, specific ranges of perturbations were modelled to be attributed to the systems at low and high frequencies. The optimization techniques considered are Method of Inequalities (MoI), MATLAB Optimization Toolbox commands *fmincon* and *fminsearch*, and H_∞ and μ synthesis strategies. Decentralized controllers were designed using IMC tuning relations (or SIMULINK auto-tuning facility) and fixed-structure H_∞ design strategy. The former was optimized using MoI, *fmincon* and *fminsearch* at different instances. Optimal centralized controllers were also designed using H_∞ and μ synthesis strategies. The performance of each controller was assessed by calculating the Structured Singular Value for robust stability and performance, the IAE values during unit step changes and observing other transient response characteristics such as rise-time, settling time, overshoot, interaction and disturbance rejection.

The results show that the efficiency of MoI decreases with increasing number of parameters to be optimized unlike *fmincon* which works better with more parameters and may rather appear "aggressive" on simple systems with few parameters to be optimized; such systems attain good rise-time but may not eventually settle fast as desired. Meanwhile, both strategies require starting parameters for optimization. Centralized H_∞ and μ syntheses were reliable strategies for obtaining robust controllers even for complex systems (systems of large dimensions, high order, great interactions and/or time-delayed terms) but in most cases resulted in controllers of high order. Controller order reduction was undertaken whenever closed loop performance degradation was not significant. Fixed-structure H_∞ controllers were found to be good alternatives but as expected, their performance did not exactly match those of the full controllers. In general, controllers synthesized with H_∞ and μ strategies under a given bandwidth (ω_B^*) constraint were found to have slower responses compared to those optimized with MoI and *fmincon* with the same constraint.

The study concluded that optimal ω_B^* values are best obtained for simple systems by optimizing alongside with controller parameters using MoI while for complex systems, much improvement may not be achievable upon the value obtained from the sensitivity plot of initial controller. It is also concluded that H_∞ and μ syntheses should be reserved for complex systems for which multiloop MoI optimization, *fmincon* optimization and fixed-structure H_∞ synthesis fail to attain desired performance.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Mathematical modeling plays a crucial role in engineering. It is more or less a sole tool for representing real existing systems, specifying desired properties and manipulating existing parameters to obtain a predetermined performance, or at least something close enough to it. It is however unfortunate that ideal models that perfectly represent real systems are often difficult to arrive at and managed during computations. Skogestad and Postlewaite (2001) identified the following as possible origins of deviation of a model from the plant it represents;

a. There are always parameters in the linear model which are only known approximately or are simply in error.
b. The parameters in the linear model may vary due to nonlinearities or changes in the operating conditions.
c. Measurement devices have imperfections. This may even give rise to uncertainty on the manipulated inputs, since the actual input is often measured and adjusted in a cascade manner. For example, this is often the case with valves where a flow controller is often used. In other cases limited valve resolution may cause input uncertainty.
d. At high frequencies even the structure and the model order is unknown, and the uncertainty will always exceed 100% at some frequency.
e. Even when a very detailed model is available we may choose to work with a simpler (low-order) nominal model and represent the neglected dynamics as “uncertainty”.

f. Finally, the controller implemented may differ from the one obtained by solving the synthesis problem. In this case one may include uncertainty to allow for controller order reduction and implementation inaccuracies.

The above sources of uncertainty were further grouped into two main classes; (1) Parametric uncertainty and (2) Neglected and unmodelled dynamics uncertainty.

Besides the deviations of a mathematical model from the physical system it represents, real systems are also subject to external disturbances which can upset the system if not well managed. According to Gu *et al.* (2005), a control system is *robust* if it remains stable and achieves certain performance criteria in the presence of possible uncertainties.

To assess the robustness of a particular system, it is necessary that the uncertainties are correctly quantified and applied to the nominal system as perturbations. In the frequency domain, these are expressed in terms of weights which specify some additional frequency characteristics that should be expected besides those exhibited in the available plant model. Also, the desired performance of the perturbed system in question may be expressed as another weight for easy frequency domain analyses of the control system.

Often, the control engineer must reach a compromise between desired performance and the range of uncertainty a system can accommodate. This conclusion many times is not easily arrived at without carrying out some iterations which may be quite mathematical and tedious. Several algorithms have been proposed over the years for carrying out such optimization processes and many of these can be implemented using MATLAB, a software readily available to the average control engineer.

1.2 Statement of Research Problem

Variations between real systems and mathematical models are quantified as uncertainty weights. Attainable performances are limited by range of uncertainty in systems. Optimization techniques in process control have strengths and limitations in the ease of obtaining controllers meeting optimal performance requirement in the face of uncertainties. Hence this study.

1.3 Objectives of the Project

The specific objectives of the research are to

1. explore standard ways of quantifying uncertainties in systems and assessing controller performance in the frequency domain;
2. examine specific robust process control strategies;
3. implement the above strategies on typical multivariable systems; and
4. determine the strengths and limitations of each strategy.

1.4 Scope of the Project

In this work, MATLAB was used to analyze the frequency behaviour of uncertain multivariable systems and the uncertainty regions were expressed as weights added to the