An Interval Analysis Algorithm for Automated Controller Synthesis in QFT Designs

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Outline

- Salient Features
- Introduction to QFT
- Problem definition
- Examples
- Conclusions
Salient Features

◆ Design is fully Automatic.
◆ Enables the designer to pre-specify the controller structure.
◆ Deals directly with the numerical values of the possibly nonconvex, nonlinear QFT bounds.
◆ Guarantees the globally optimal solution, if the solution exists.
Introduction

2-DOF Structure for QFT formulation
Introduction ...

QFT Objective:

Synthesize $K(s)$ and $F(s)$ for the following specifications:

- Robust Stability margin
- Tracking performance
- Disturbance Attenuation
Introduction …

QFT Procedure:

1. Generate the plant template at the given design frequencies $\omega_i$.

2. Generate the bounds in terms of nominal plant, at each design frequency, on the Nichols chart.
Introduction ...

QFT Procedure ...

3. Synthesize a controller $K(s)$ such that
   1. The open loop response satisfies the given performance bounds,
   2. And gives a nominal closed loop stable system.

4. Synthesize a prefilter $F(s)$ which satisfies the closed loop specifications.
Problem Definition

Given an uncertain plant and time domain or frequency domain specification, automatically synthesize an optimal QFT controller of a pre-specified structure.
Example 1

◆ Application: Control system design for DC Motor.
◆ Compared with: Genetic Algorithms*.

◆ No. of optimization variables involved: 4
◆ Reduction obtained with the proposed algorithm:
  – hf gain: 48.73%
  – Cutoff freq: 67.68%
Example 2

◆ Application: Control system design for DC Motor.

◆ Compared with: Non-iterative method based on SVD*.

◆ No. of optimization variables involved: 3

◆ Reduction obtained with the proposed algorithm:
  - hf gain: 10.63%
  - Cutoff freq: -21.87%
Example 3

- **Application:** Control system design for DC Motor.
- **Compared with:** LP solver NAG E04MBF*.
- **No. of optimization variables involved:** 5
- **Reduction obtained with the proposed algorithm:**
  - hf gain: 23.80%
  - Cutoff freq: 12.41%
Example 4

◆ Application: Control system design for DC Motor.
◆ Compared with: LP solver*. 
◆ No. of optimization variables involved: 6
◆ Reduction obtained with the proposed algorithm:
  – hf gain: 73 %
  – Cutoff freq: 65 %
Example 5

◆ Application: Control system design for Aircraft.
◆ Compared with: SQP solver IMSL DNCONG*.
  – D. F. Thompson, “Optimal and Sub-optimal loop shaping in QFT”, PhD thesis, School of Mechanical Engineering, Purdue University, USA, 1990
◆ No. of optimization variables involved: 5.
◆ Reduction obtained with the proposed algorithm:
  – hf gain: 53.18 %
  – Cutoff freq: 30 %
Example 6

◆ Application: Control system design for Aircraft.
◆ Compared with: SQP solver IMSL DNCONG*.
◆ No. of optimization variables involved: 7.
◆ Reduction obtained with the proposed algorithm:
  – hf gain: 48.69 %
  – Cutoff freq: 86.35 %
Conclusions

- An algorithm has been proposed to automate the controller synthesis step of QFT.

- Proposed algorithm is based on deterministic interval global optimization techniques that assures convergence and the globalness of the solution.

- The proposed algorithm uses the precise values of the numerical QFT bounds which avoids the problem associated with the approximation of the bounds.

- Overall, a reduction of 73% in hf gain and 86% reduction in cutoff frequency of the controller is obtained, over the existing methods for QFT controller synthesis.
Thank you!