An Interval Analysis Algorithm for Automated Controller Synthesis in QFT Designs

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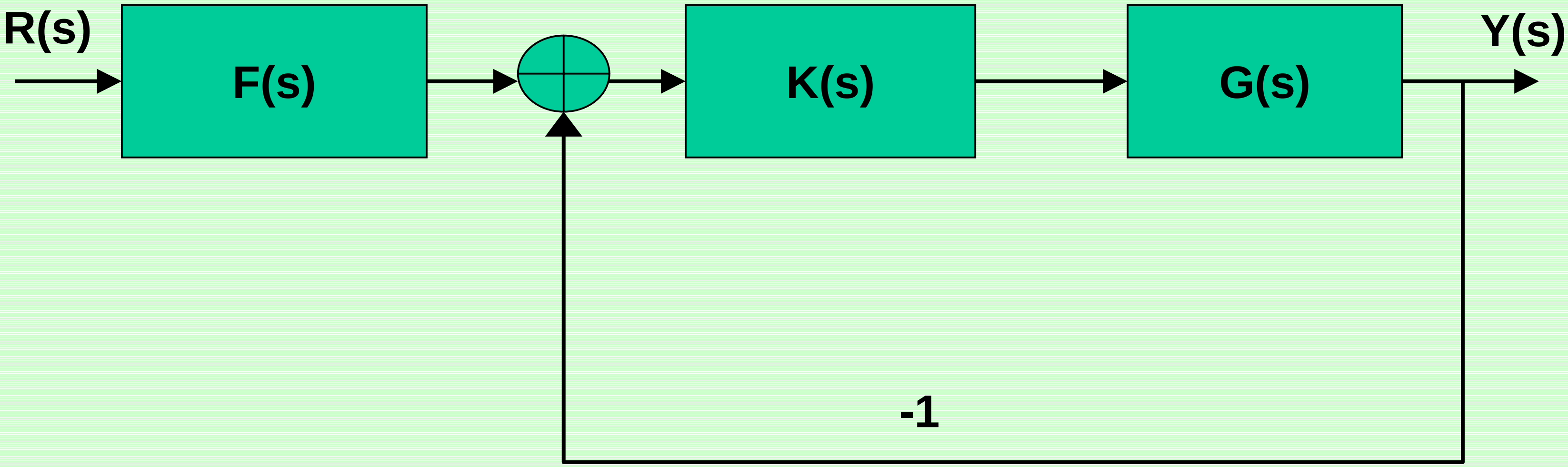
Outline

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

Salient Features

- Design is fully Automatic.
- Enables the desinger 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 ω_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*.**
  - ** W. Chen et al. "Automatic Loop-shaping in QFT using genetic algorithms", In Proceedings of 3rd Asia-pacific Conference on Control and Measurement, pages 63-67, 1998.*
- **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*.**
  - *A. Zolotas and G. Halikias, "Optimal design of PID controllers using the QFT method", IEE Proc-Control Theory Appl., 146(6):585-589, Nov. 1999.*
- **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*.**
  - *G. Bryant and G. Halikias, "Optimal loop-shaping for systems with large parameter uncertainty via linear programming", Int. J. Control, 62(3):557-568, 1995.*
- **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*.**
  - *Y. Chait et al., " Automatic Loop-shaping of QFT controllers via Linear Programming", Trans. Of the ASME Journal of Dynamic Systems, Measurement and Control, 121:351-357, 1999*
- **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*.**
  - *D. F. Thompson and O. D. I. Nwokah, "Analytical loop shaping methods in QFT", Trans. Of the ASME Journal of Dynamic Systems, Measurement and Control, 116:169-177, 1994.*
- **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 !