Comparison QFT Controller Based on Genetic Algorithm with MIMO Fuzzy Approach in a Robot

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Abstract

In this paper, a practical method to design a robust controller for a two-arm manipulator using Quantitative Feedback Theory (QFT) using GA is proposed. Robot manipulators have multivariable nonlinear transfer function, implementation of QFT technique requires first to convert its nonlinear plant into family of linear and uncertain plant sets and then an optimal robust controller will be designed for each set. In order to illustrate the utility of our algorithm we present the application of it to a two degree of freedom robot arm manipulator. In the presented method the controller is designed directly by choosing and optimization of coefficients of transfer function by using genetic algorithm. In optimization procedure, stability and bounds of the system were considered as the constraints of the problem. Non-linear simulations on the tracking problem are performed and the results highlight the success of the designed controllers. The results indicate that applying the proposed technique successfully overcomes the obstacles to robust control of non-linear a robot. Lastly designed controller with QFT method is compared with Fuzzy controller and it is shown that QFT technique suggests a controller which has a better control performance.

Key words: Two Arm Manipulators, Fuzzy Controller, QFT Controller, Genetic Algorithm.

1. Introduction

The purpose of a robot is to control the movement of its gripper to perform various industrial jobs such as assembly, material handling, painting, and welding (Luh, J. (1983)). Robot manipulators have complex nonlinear dynamics that might make accurate and robust control difficult. Fortunately, robots are in the class of Lagrangian dynamical systems, so that they have several extremely nice physical properties that make their control straight forward (Lewis, F.L. (1999)). There are several methods for controlling of a robot such as: classical joint control, digital control, adaptive control, robust control, learning control, force control, and teleoperation. In this paper we consider the two arm manipulators as a two degree of freedom nonlinear multiple-input multiple-output (MIMO) system and as a controlling technique Quantitative Feedback Theory (QFT) will be used.

There are many practical systems that have high uncertainty in open-loop transfer functions which makes it very difficult to have suitable stability margins and good performance in command following problems for the closed-loop system. Therefore a single fixed controller in such systems is found among "robust control" family.

Quantitative Feedback Theory (QFT) is a robust feedback control system design technique introduced by Horowitz (Horowitz. I M. (1991)), which allows direct design to closed-loop robust performance and stability specifications.

2. Dynamic equations of the robotic manipulator

Fig.2 depicts a two degree of freedom robot, where m_1, m_2 are the masses of links 1, 2 and l_1 , l_2 are the length of the links 1, 2 respectively. The dynamic equation of the robotic manipulator is (Jing Lian, R. (2005)).

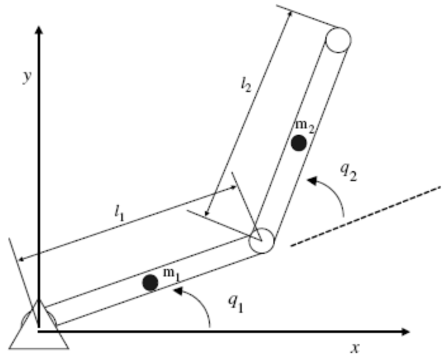


Fig 1: Two link robotic manipulator

$$M(q)\ddot{q}+C(q,\dot{q})\dot{q}+G(q)=\tau \tag{1}$$

$$M(q)=\begin{bmatrix} (\frac{1}{3}m_1+m_2)l_1^2+\frac{1}{3}m_2l_2^2+m_2l_1l_2\cos q_2 & \frac{1}{3}m_2l_2^2+\frac{1}{2}m_2l_1l_2\cos q_2 \\ \frac{1}{3}m_2l_2^2+\frac{1}{2}m_2l_1l_2\cos q_2 & \frac{1}{3}m_2l_2^2 \end{bmatrix}$$

$C(q,\dot{q})$ is a 2×2 matrix of coriolis and centrifugal forces that can be described as:

$$C(q,\dot{q})=\begin{bmatrix} -\frac{1}{2}m_2l_1l_2(2\dot{q}_2) & -\frac{1}{2}m_2l_1l_2\dot{q}_2\sin q_2 \\ \frac{1}{2}m_2l_1l_2\dot{q}_1\sin q_2 & 0 \end{bmatrix}$$

And $G(q)$ is a 2×1gravity vector that can be represented as:

$$G(q)=\begin{bmatrix} (\frac{1}{2}m_1+m_2)gl_1\cos q_1+\frac{1}{2}m_2gl_2\cos(q_1+q_2) \\ \frac{1}{2}m_2gl_2\cos(q_1+q_2) \end{bmatrix}$$

Where g represents gravity acceleration constant.

The following numerical values are chosen for the robot manipulator (m1=2kg, m2=3kg, L1=0.4m and L2=0.6m) (Jing Lian, R. (2005)).

Block diagram representation of the above equations which simulates nonlinear multivariable dynamics of robot in Matlab is show in Fig 2.

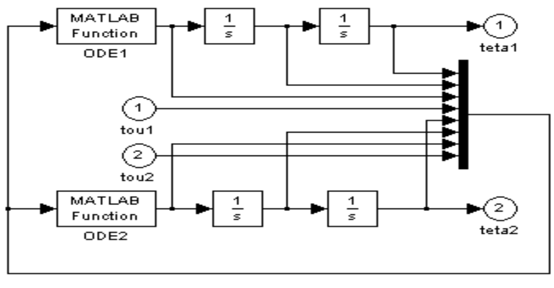


Fig 2: Simulation of Robot Dynamic in Matlab

2.1 Linearization

In QFT method, the nonlinear plant is converted to family of linear and uncertain processes. For this purpose, literature on QFT offers two different techniques (Amiri-M, A-A. (2009)). namely Linear Time Invariant Equivalent (LTIE) of nonlinear plant, and Non Linear Equivalent Disturbance Attenuation (NLEDA) techniques. In both methods, limited accepted output is the main tool to translate nonlinearities of the plant into templates for the first technique, or disturbance bounds for the second technique.
In result linearized transfer function for each arm can be obtained as follows

$$P_i = \frac{1}{s(J_{eff}\,s + C_{eff})} \quad \text{i=1, 2} \tag{2}$$

By running the simulation for multiple trajectories of all arms, J_{eff} and C_{eff} are found respectively.

1) First Link:

$$J^{eff} = [5.3838\ 7.3716] \text{ and } C^{eff} = [27.9061\ 55.7397] \tag{3}$$

2) Second Link:

$$J^{eff} = [3.1258\ 4.1913] \text{ and } C^{eff} = [-.3417\quad 17.4859] \tag{4}$$

2.2 QFT CONTROLLER DESIGN

The QFT design methodology is quite transparent, allowing the designer to see the necessary trade-offs to achieve the closed-loop system specifications. The basic steps of the procedure are presented in the following sub-sections. They are:

- Plant model (with uncertainty), Templates generation and nominal plant selection Po(jω).
- Performance Specifications.
- QFT Bounds B(jω).
- Loop-shaping the controller G(jω).
- Pre-filter synthesis F(jω).
- Simulation and Design Validation.

Using QFT method introduce by Zoloas, A.C (1999), Nataraj, P.S.V. (2002), and Horowitz, I. M. (1992) for controlling of plants. The nonlinear plant needs to be converted to family of linear and uncertain processes implementing the new technique mentioned before.
A suitable QFT controller (G) and prefilter (F) (Fig.3) were then designed for the four joints to satisfy the closed loop specifications ((M_p=20%) and (T_s=0.08 s) where M_p and T_s are the overshoot and the settling time respectively).

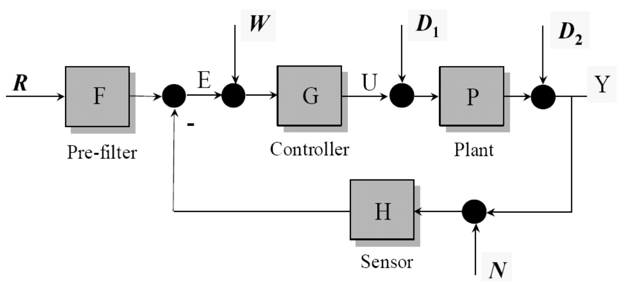


Fig 3: Structure of a Two Degrees of Freedom System

Note: To save the space, all stages of designing the controller demonstrate for first link. Template generation (reveals frequency domains Fig.4); robust margins for five selected trajectories and intersection of bounds of the first Arm based on frequencies found in template generation are shown in Fig.4 are presented in Figs.5, and 6 respectively.

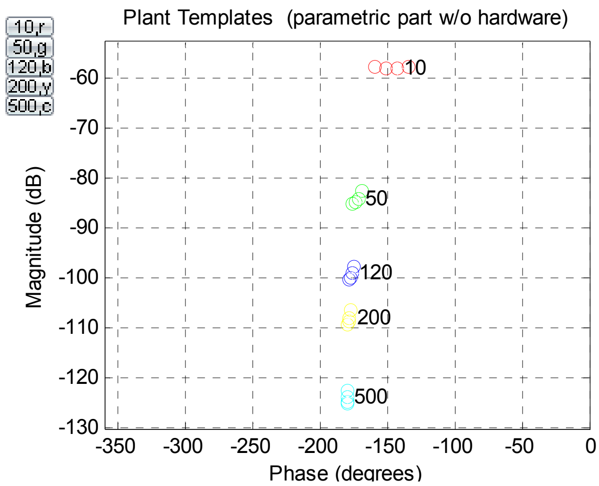


Fig 4: Template Generation

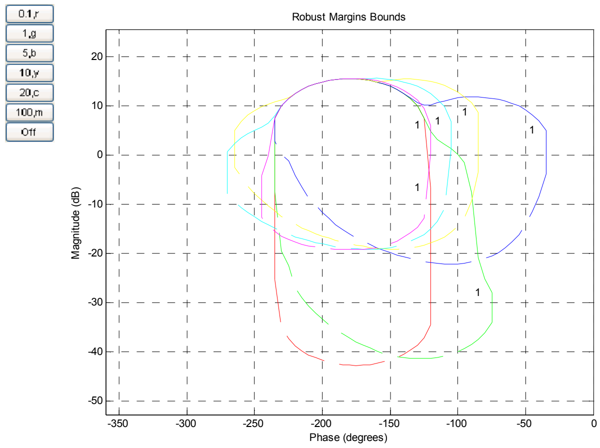


Fig 5: Robust Margin Bounds for Arm 1

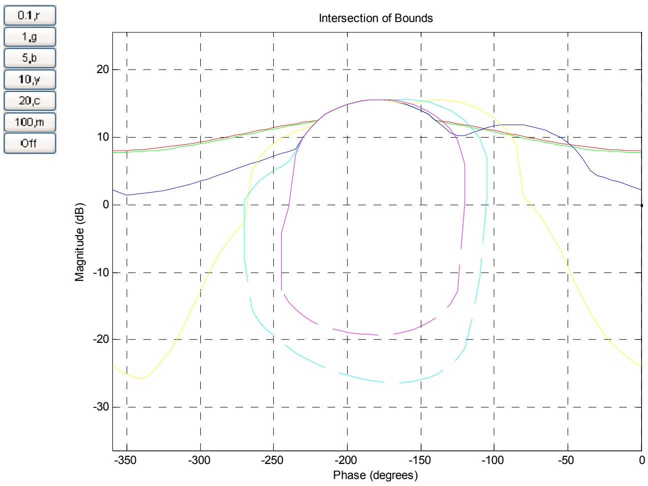


Fig.6 Intersection of Bounds for Arm 1

2.3 QFT Controller Design using GA

The optimum in QFT is taken to be any L (jω) whose magnitude as a function of frequency decreases as fast as possible (Zoloas, A.C (1999)).
Evolutionary computation is the most powerful computational intelligence technique. This soft-computing technique uses computational redundancy to form an effective population of candidate solutions.
The genetic algorithm (GA) is the most representative evolutionary algorithm, which can encode, and hence optimize, both parameters and structures of an engineering solution. A GA mimics human intelligence in trial-and-error based learning and tuning. It incorporates self 'survival-of-the-fittest' selection and replication principle and requires no teacher or gradient information.
After replicating better performing candidates, the GA then diverges the search in an operation called 'crossover' by exchanging co-ordinates or parameters among surviving candidates. It also diverges the search by altering some parameter values in an operation called 'mutation'. This way, a new 'generation' of candidate designs will be formed and the emulated evolutionary cycle continues until no meaningful improvements in the design may be found.
In this paper, an automatic loop-shaping algorithm is used for coupling up advantages of a classical manual loop-shaping method to those of GAs. From the manual loop-shaping method, the characteristic and/or advantage of the proposed method as follow.

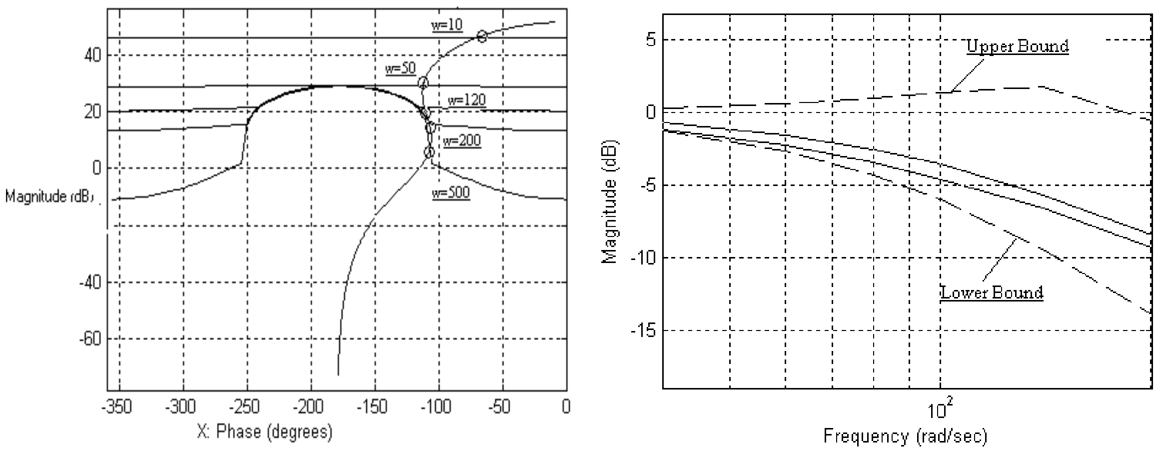


Fig 7: Loop-Shaping and Pre-Filter In Nichols Chart for Arm**1**

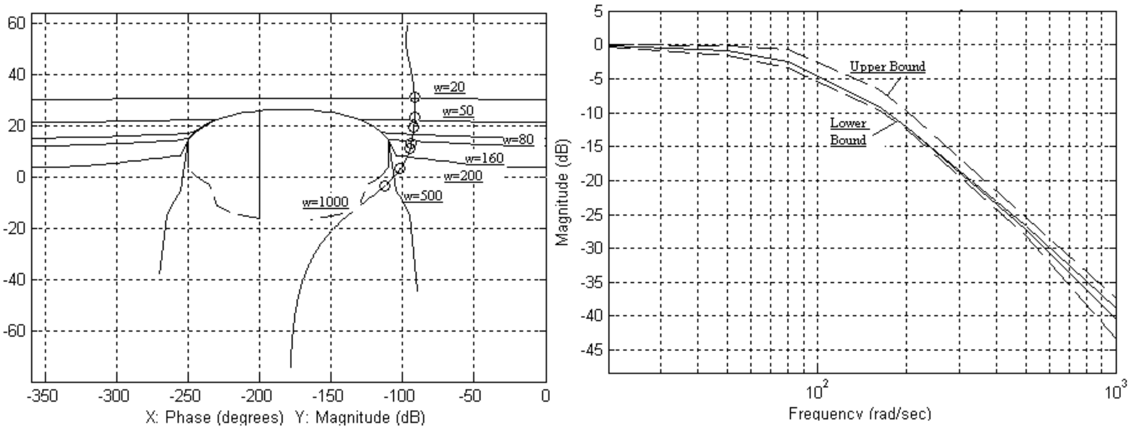


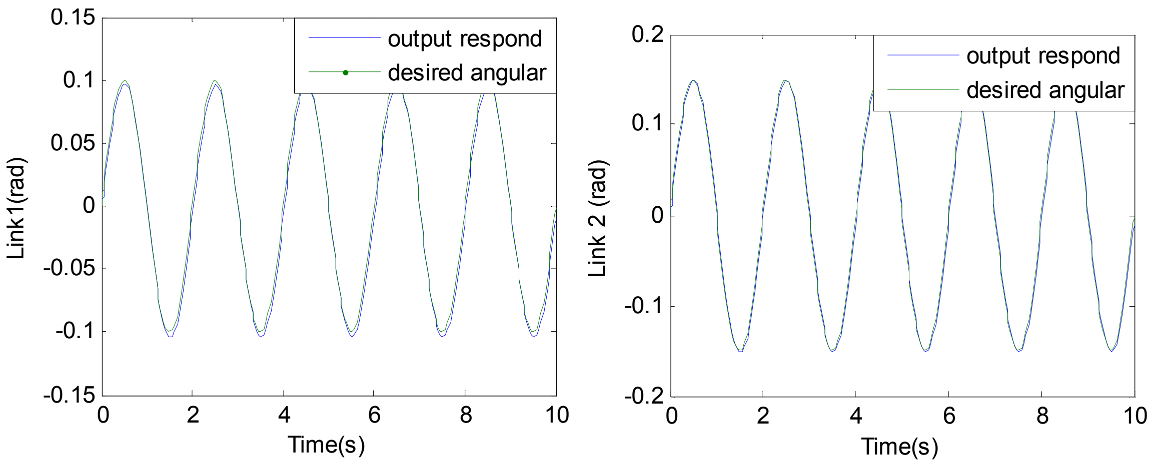
Fig 8: Loop-Shaping and Pre-Filter In Nichols Chart for Arm**2**

The respected controller and prefilter for arm (1) and (2) are found respectively as follow:

$$G(s) = 238.33\frac{s(s+77.58)}{\left(\frac{s}{26.76}+1\right)\left(\frac{s}{2213}+1\right)} \qquad F(s) = \frac{138.1^2\left(\frac{s}{204.3}+1\right)}{\left(\frac{s}{122.1}+1\right)\left(s^2+207.15\,s+138.1^2\right)} \tag{5}$$

$$G(s) = 3033.3\frac{(s+2.012)}{\left(\frac{s}{2444}+1\right)} \qquad F(s) = \frac{107.5^2\left(\frac{s}{1542}+1\right)}{\left(s^2+181.1\,s+107.5^2\right)} \tag{6}$$

Angular tracking responses were used to evaluate the control performance of the robotic system. Fig. 9 plots the simulation angular tracking responses of this control system using QFT controller.



a) **b)**

Fig: 9 Angular tracking response using a QFT: (a) the first, and (b) the secondary link.

3. Fuzzy controller

3. 1 Introduction of fuzzy controller

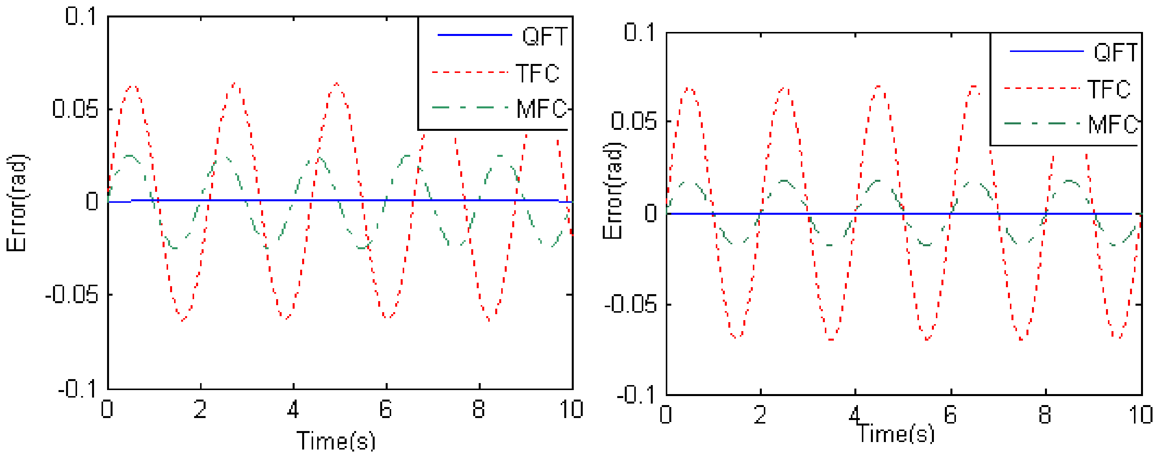
For dealing with nonlinear effects, uncertainties and other imperfections of such a nonlinear system, various approaches have been proposed. The traditional fuzzy controller (TFC), requiring relatively low computational and programming capacity to represent human control behavior, has been widely used in many engineering applications in recent years. Since, the fuzzy controller is an approximate reasoning-based system without an analytic model for stability and robustness evaluation, the commercial industrial application is hesitated. This problem can be solved by introducing mixed fuzzy control (MFC) (Jing Lian, R. (2005)), Sliding-mode control (Utkin VI. (1977)) and adaptive fuzzy controller (Ching Chiou, K. (2005)).

3. 2 TFC and MFC controller

For control a two link robotic manipulator by fuzzy controller with minimum error, we need two fuzzy controllers. Initially, only a TFC was designed for each link, to control this MIMO robotic system. Secondly, a coupling fuzzy controller was applied into the traditional fuzzy control strategy to improve the control performance of this MIMO robotic system (Jing Lian, R. (2005)).

4. Results and Analysis

To select the best method of control, QFT controller based on GA with fuzzy approach (Jing Lian, R. (2005)) in control of two arm manipulators are compared.
Angular tracking responses were used to evaluate the control performance of the robotic system. Fig. 10 compares the angular tracking errors of TFC, the MFC and the QFT methods.



a) b)

Fig: 10 Comparison of the TFC, the MFC and the QFT methods for angular tracking errors (a) the first link and (b) the secondary link

Finally, Fig10 (a, b) compares QFT method with Fuzzy controller and shows that QFT technique suggests a controller which has a better control performance (robustness, stability, tracking).

5. Conclusions

In this paper, a practical method to design a robust controller for a robot using quantitative feedback theory (QFT) is proposed. The presence of uncertainty in the dynamics of robot arm manipulators means that the application of robust control methods to achieve a high accuracy in tracking is inevitable. QFT has been used to design a robust controller for a robot. The basic design steps can be summarized as the linearization of the robot dynamics, the design of suitable robust performance bounds by minimization of a sensitivity function, linear simulation, and nonlinear simulation.
To solve the QFT design problems that a practical engineer faces, a GA based computer automated design procedure has been developed. This can be applied to provide an initial controller quickly on which to base manual loop-shaping and refinements. This is particularly helpful with unstable or non-minimum phase plants or plants for which it is difficult to find a stabilizing controller.
Also, QFT method is compared with Fuzzy controller and it is shown that QFT technique suggests a controller which has a better control performance.

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