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QFT CONTROLLER FOR NONLINEAR SYSTEM APPLICATION TO 3-DOF FLIGHT CONTROL MODULE

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ABSTRACT

In this paper we proposed a new control method based on Quantitative Feedback Theory (QFT) to design practical controller methodology for uncertain characterized with three degree of freedom flight control module. Again linearly least phase systems must sacrifice to desirable feedback control benefits to avoid an excessive uncertain disturbance. While preserving the robust stability Quantitative Feedback Theory (QFT) controller is proposed to control highly uncertain plants. A 3-DOF flight control system is intrinsically nonlinear, unstable and totally uncertain because of the nature of three individual angles known as pitch, elevation and travel. Most controllers which are designed for 3-DOF helicopter flight systems are base on a minimal linearized model where system variants and uncertainties are not accommodated. Again, the controllers are mostly designed to gratify the gains and phase margin specifications that may not guarantee to handle the sensitivity. In proposed controller QFT may explicitly deal with uncertainty, where large plant parameter uncertainties with lower bandwidth can be achieved by QFT controller. Pre-filter technique may improve both robust stability and robust tracking performance within a desired precision of the individual uncertain parameters of 3-DOF module. This controller may handle large parameter uncertainties and disturbance with rugged stability. The random optimization technique is engaged in the design to optimize the overall performance of the controller. Simulation results and equations are used to show effective result of the proposed control methodology.

Keywords: QFT controller, quantitative feedback theory, 3DOF helicopter, uncertainties, pre-filter, stability.

INTRODUCTION

Recently research on 3-DOF helicopter became more popular because of its nonlinearity, time inconstant and strong coupling system. Traditional controllers, which based on the linear concept, can be used for unsafety models and can show perform well in a small work area but the flight tracking control study of 3-DOF helicopter became one of classic research purpose in the control system. 3 DOF helicopter is a experimental platform which presents quite interesting control challenges with simplified and benchmark testing performance based on nonlinearities to find the effectiveness of various flight controllers. The objectives of the controller are to control three angles of the helicopter following the desired values. The tracking control of 9 unmanned aerial vehicles) UAV helicopter has been studied with the composited Quantitative feedback control system. To build a test bed for UAV helicopter Quanser developed a device named 3-DOF helicopter. The particular features of this device are nonlinearity, uncertainty, unmolded dynamics, disturbances, measurement noise etc. and proven subject for the design of nonlinear feedback controllers.

Done a comparative study on the performances of travel angle of a 3-Degree-of-Freedom (3-DOF) Quanser bench-top helicopter using standard PID and adaptive PID controllers, researchers found that performance of the PID controller is good whether its performance could be better-quality if the controller is combined with adaptive method [1]. A magnetic levitation (Maglev) model is a nonlinear and unstable because of the nature of magnetic force, so researchers proposes a robust control design method based on Quantitative Feedback Theory (QFT) and observed the performance on single degree-of freedom(DOF) maglev model to satisfy the bound of the sensitivity of it. Experiments prove that the robust QFT controller maintained stable levitation with 100% load disparity [2]. An improved robust Proportional Derivative, controller for a 3-Degree-of-Freedom (3-DOF) bench-top helicopter by using adaptive deadbeat algorithm and the output response that is fast, robust and updated online is quit expected [3]. A design method arose with self-tuning Quantitative Feedback Theory (QFT) combined with improved deadbeat control algorithm and from the tests result the efficiency of the self-tuning QFT based dead-beat controller's has updated online parameters with less percentage overshoot and low settling time with the variations in the plan [4]. To achieve robust control with pre-defined specifications, deadbeat is an algorithm that could bring the output to steady state with minimum step size. So designers presents self-tuning Quantitative Feedback Theory (QFT) by using improved deadbeat control algorithm for a grain dryer and where performance are remarkable [5]. A proposal of robust adaptive combined with Linear-Quadratic Regulator (LQR) was made to design a faster response controller for uncertain characterized 3-DOF flight control module weather successfully shown that the controller handled large number of parameter uncertainties and unknown disturbance with rugged stability [6]. A neural network-based estimated analytical controller was experimentally tested by motion control of elevation and pitch angles [7]. An adaptive controller was implemented to make the

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travel and elevation angles track the outputs of a reference model [8]. Input and state constraints were systematically accounted within the control design procedure [9]. A robust control method for approaching the regulation of laboratory helicopter was considered [10]. Robust regulation for 3Dof helicopters with external disturbance was considered but due to the difficulties of MIMO systems, it was challenging to realize the flight movements with a various reference signals [11]. Moreover, few researches focused on distributed tracking methods for MIMO model of 3-DOF helicopters [12].

PROBLEM STATEMENT AND METHODOLOGY

The following part of this paper briefly describe the "Quanser helicopter benchmark" and its dynamics followed by a formulation of the QFT output for the elevation, travel and pitch axes of the 3-DOF helicopter in Figure-1. A new design method of robust output regulator is proposed also in this section. As Figure-1 illustrated, two DC motors installed at the ends of a rectangular frame are employed to control the 3-DOF lab helicopter. The helicopter frame is free to pitch around a long arm and the long arm is suspended from a junction who has two degrees of freedom to elevate and travel. These two DC motors are called front motor and rear motor separately with independent control signals. The helicopter frame would elevate if both motors were applied with positive voltages, while it would fall with opposite ones. Moreover, it would pitch and travel if the two motors were applied with different voltages. Since merely two inputs are available for the helicopter system with it has three independent outputs, our control strategy intends to deal with tracking the elevation and pitch signals as reference.

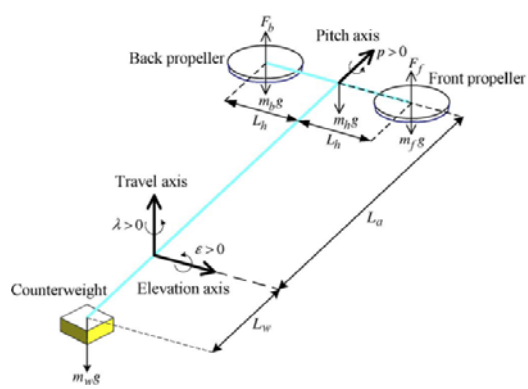

Figure-1. Free-body diagram of the 3-DOF helicopter.

To design a QFT based controller for the three angles, we designed individual controllers G with filters F according to the angle's transfer function with QFT self-tuning tool box. The filters are designed to reduce the unwanted noises from the desired inputs, where the input signals should come from parameters and variables of the sensing body. The transfer functions are derived for the angles with hardware calculations. Figure-2, Figure-3 and Figure-4 are the Math-lab simulated designed with the proposed Controllers G and filters F according to the angles with required input of constant 0.5.

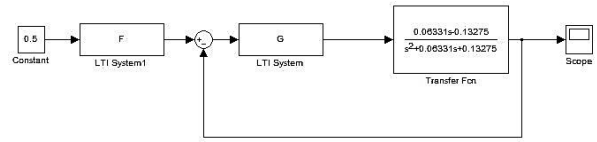

Figure-2. QFT controller design for travel angle.

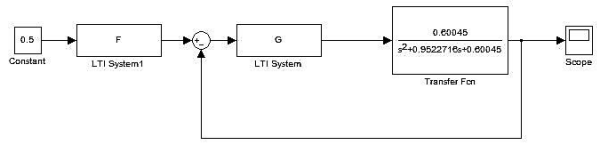

Figure-3. QFT controller design for pitch angle.

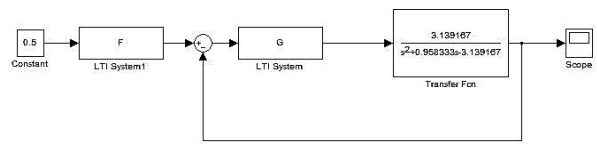

Figure-4. QFT controller design for elevation angle.

Based on three different considerable outputs we tried to combine the three angles' controllers into one common controller. After a huge number of simulations, we proposed the most effective and efficient controller for the 3-DOF system.

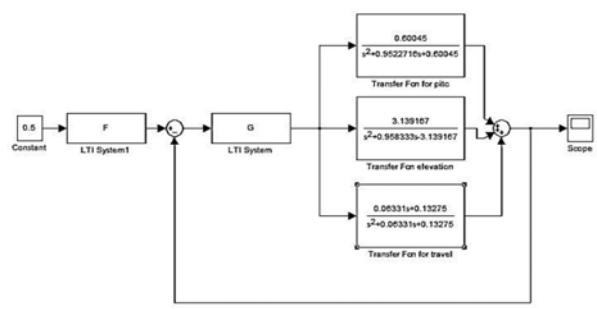

Figure-5. QFT controller design for combined three angles.

Figure-5 shows the design of control diagram with new Controller G and filter F controlling the three angles all together.

RESULTS AND DISCUSSIONS

Tests have been conducted in Matlab and Simulink environment. Three different controllers have been tested on the 3-DOF, with the same working platform

with other controller for benchmark. As can be seen, all three controllers are able to follow desired input line. In Figure-6 for the travel angle, there is a peak in the first step due to fast stabilization of the process output but have steady state error of 10%. From this Figure-7 it can be seen that the emerging of QFT specifications for pitch angle a large peaks in the output response and following 13% steady state error. In the third elevation angle test, from Figure-8 we found the capability of the QFT controllers with high overshoot and the characteristic of 13% error approximately. These are the main disadvantage of QFT controller but the steady state errors are because of the filters F. When filters aligned with QFT specifications, the QFT produce first response with considerable overshoot but faster settling time with steady state error. But we found the best controller responses recorded in Figure-9, where shown the QFT self-tuning controller have the ability to control all three angles with a little overshoot and no steady state error whether filters effect also applied. The learning mechanism of the controller improves the number of sampling events increases and better response. The performance of QFT-based controller is consistent throughout the test, because it is an offline controller. This test shows the capability of QFT-based controller can be adapt to any changes occurred in the plant. The fourth test reveals the superiority of the proposed self-tuning QFT-based controller where the plant experiences the maximum 20% parameter variation/uncertainty at the time T=300s. The new parameters values are Gain K = 0.187; Tw = 0.340; ζ = 0.184; Td = 27.027; Tz = 0.495. When applying controller using standard QFT-based algorithms alone, the response produced unwanted peaks with small settling time with high steady state errors. The proposed system is able to attenuate the disturbance in the form of parameter variation effectively by the filters.

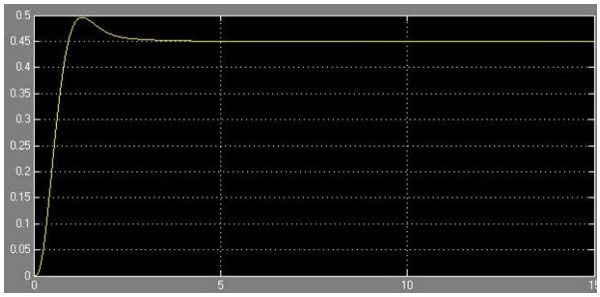

Figure-6. Travel angle output.

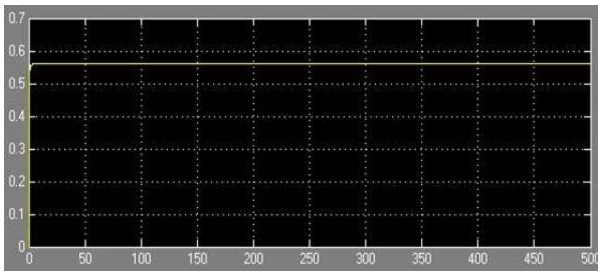

Figure-7. Pitch angle output.

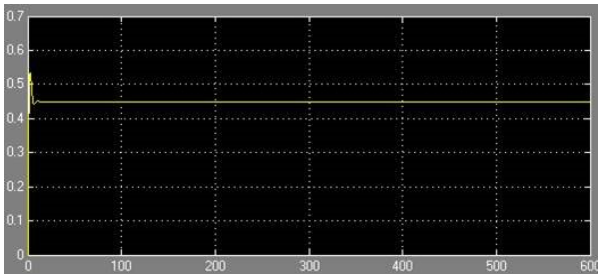

Figure-8. Combined angle output.

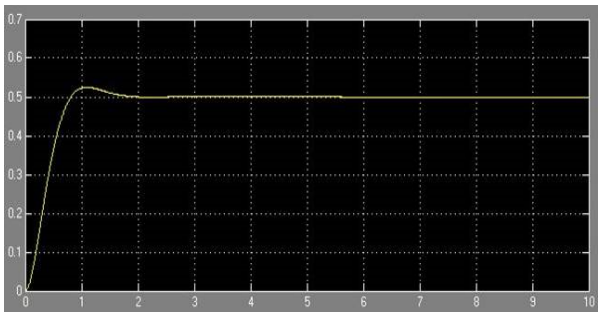

Figure-9. Elevation angle output.

CONCLUSIONS

In this research, a QFT controller which combines with filters has been developed and proposed to realize the attitude control of a 3DOF helicopter. The proposed controller was tested on a nonlinear bench top helicopter for three angles control. A large uncertainty may imply a poor tracking performance to avoid an excessive rate of feedback, which would saturate the actuators, and guaranteeing an acceptable robust stability. The solution proposed was to suitably divide the uncertainty region. Simulation and experiment results validate that the integral action can eliminate the tracking errors of the model uncertainty effectively. The proposed controller also has the capability where the controller can adapt to any changes occurred to the plant and it has produced better control respond compared to the existing PID or LQR controllers.

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