DESIGN OF A CONTROLER FOR A LOAD SIMULATOR WITH COMPARATIVE ANALYSIS USING PID & QFT ALONG WITH REALTIME SYNTHESIS

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ABSTRACT: This paper presents the novelty of a robust control technique, QFT, over PID tuning methodology and a relatively conventional controller embedded through a microcontrollerATMEGA32 on a temperature controller unit for a hydraulic load simulator. The newer algorithms of bound computations have been implemented in QFT technique. And the comparative analysis of their performances is also shown in this paper. The controller developed by QFT is not only simpler than others but also easy implementable. The hardware model has also been developed using microcontroller unit and associated figures are attached herewith.

KEYWORDS: QFT, bounds, PID tuning, templates, tempareture controller, load simultor.

INTRODUCTION

The dynamic road simulator is used to represent the fatigue load of the vehicle. It consists of a hydraulic pump, servo valve, hydraulic actuator and its control equipment. The temperature is a crucial issue for a safe handling of this load simulator. The PID controller is widely used for the hydraulic and temperature control. Assuming a LTI plant model, this control can be used although much iteration is needed to achieve the accurate control effects. As the hydraulic system used for the road simulator inherently possesses the system uncertainty & nonlinearity, this problem should be taken care of by another robust control algorithm. In QFT, controllers are designed to satisfy the uncertain plant dynamics and external disturbance after loop shaping &Prefilter design using QFT toolbox in MATLAB environment [6], the final results are verified for performance specifications given in [3]. The standard results for PID controller are alsocompared to the QFT outputs.

PROBLEM DEFINITION

Plant Description

The modeling has three parts for a load simulator: servo valve, hydraulic actuator satisfying continuum equation of oil flow, and load relation from the mechanical cylinder. The resulting simplified transfer function of the plant model for controller synthesis can be represented as: $\boldsymbol{P(s)} = \frac{359.6}{as^3+bs^2+cs+d}$

Where a, b, c, d indicate uncertain cylinder parameters & their ranges are given as a $\in$ [2.147e-6, 6.135e-6], b $\in$ [0.01333, 0.06777], c $\in$ [0.03647, 0.05131], d$\in$[0.01904, 0.03388]

Over all control structre for QFT and PID

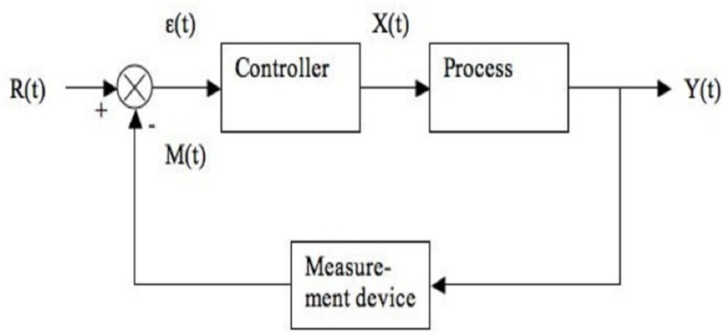


Figure 1: Overall control structure

PERFORMANCE SPECIFICATIONS AND DESIGN PROCEDURE

Tracking specifications:

Overshoot : < 21%

Rising Time : 0.478s $\leq t_r \leq$ 1.02

Settling Time : $t_s \leq$ 1.85 s

Steady State Error : Nil

The selected nominal plant is

$$Po(s) = \frac{359.6}{2.54e{-}6s^3 + 0.06777s^2 + 0.04983s + 0.019404}$$

Robust stability performance:

$$\left|\frac{P(s)G(s)}{1+P(s)G(s)}\right| \leq W_{s1} = \gamma = 1.2 \ (=1.58\text{dB}) \text{ for all } \omega \geq 0 \ .$$

The computed and reference upper and lower bounds [4] for the plant are shown below.:

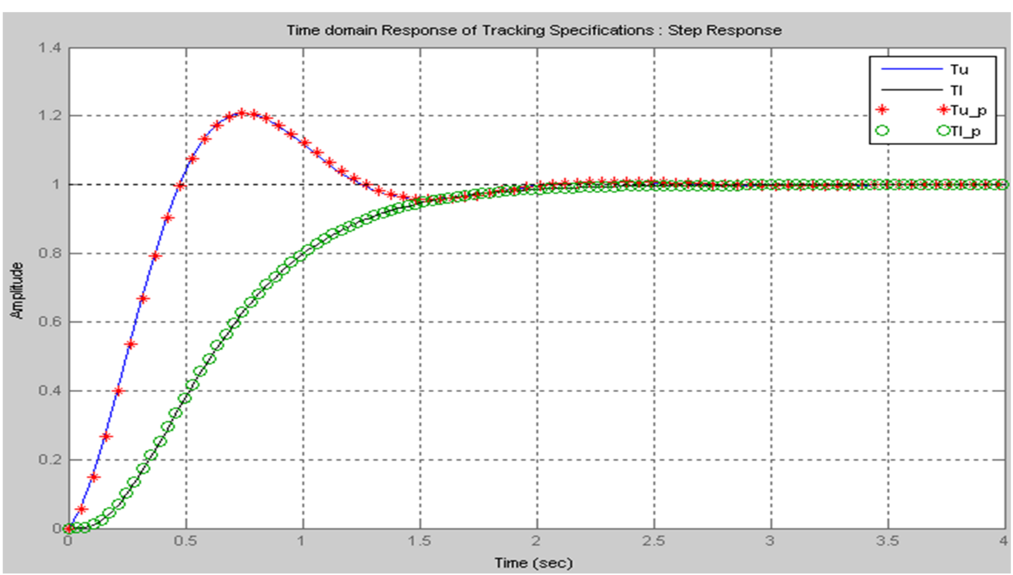


Figure 1:Time Response of Tracking Specifications (Obtained tracking spec. & given spec.)

Template and Bound computations

This design process is carried out by Template and Bound Generation. When the system is not defined by a single model due to the parametric uncertainty, the frequency responses of the system for a given frequency is represented by a set of points, as many different models are there. All of these points define a region of uncertainty known as ***Template.***

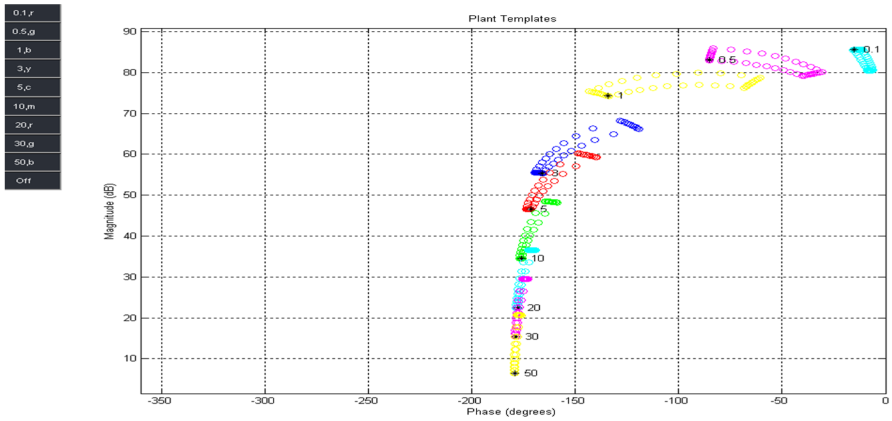


Figure2: Plant Templates using Kharitonov Segment Methods[8]

The resulting bounds of robust stability using envelop method [7] as shown as follows.

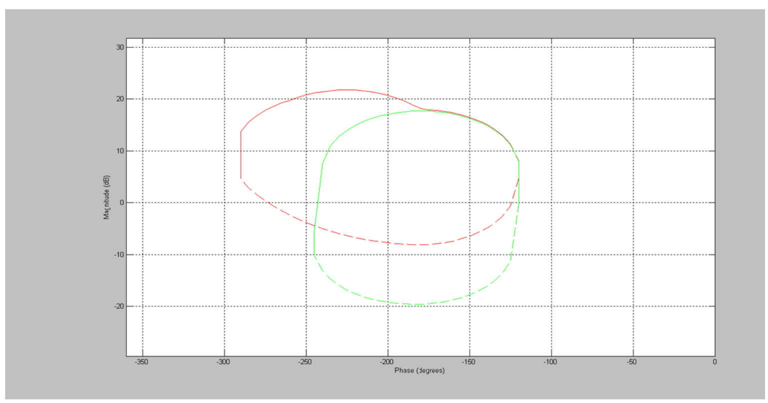


Figure 4. Robust margin bounds by Envelop method

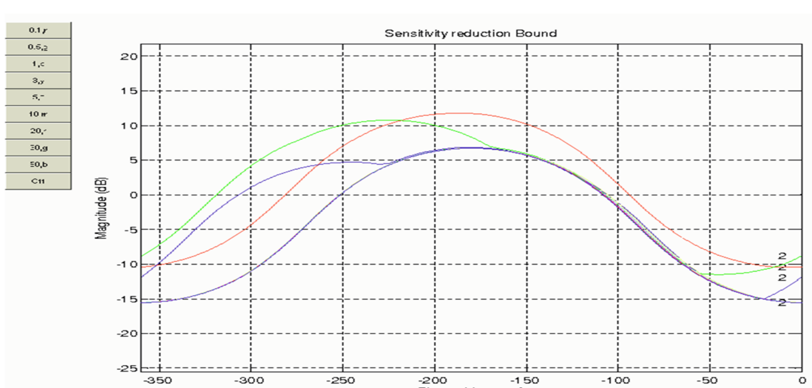


Figure 5. Sensitivity Reduction Bound by Horowitz-Sidi Method

The tracking specification is established by means of lower, $T_{RL}(s)$, and upper, $T_{RU}(s)$ bounds in the system response. In order to apply the QFT technique, this specification is defined in the frequency domain as follows

$$T_{RL}(s) \le \frac{F(s)G(s)P(s)}{1+P(s)G(s)} \le T_{RU}(s)$$

P(s) = plant transfer function, F(s)=prefilter, G(s)= controller designed.

The resultant intersections of robust stability bound, sensitivity bounds and tracking bounds are defined as composite bounds and using this the design process of a controller starts with loop-shaping. The initial design starts with an integrator and the iteration continues.

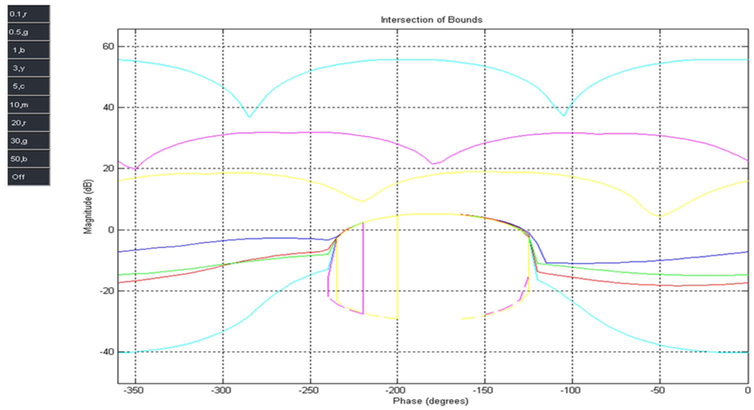


Figure 6: Composite bound for loop shaping

Controller and Prefilter synthesis

The next step in the design of the control system is to find out a controller with which all of the desired specifications can be fulfilled. It is also known as the synthesis or "loop-shaping" phase. The adjustment is made using the Matlab QFT Toolbox, shifting the loop curves vertically and horizontally on the magnitude-Phase plane, until it is situated in such a way as not to violate the bounds and so as to have the lowest possible gain. The representation of the loop function $L_o(s)$ is a curve with several points. These points correspond to the response of the loop for the various frequencies defined in ω.Composite of all bound / Intersection of group bounds must exist at design frequencies. The loop adjustment must be done in such a way, so that at each frequency point, nominal loop $L_o(s)$ is close to the (greater than or equal to) bound of at same frequency. After completing the loop shaping the resultant controller that are obtained as

$$G(s) = \frac{0.007\ (s^2 + 1.85s + 1)}{s\ (\frac{s}{86} + 1)}$$

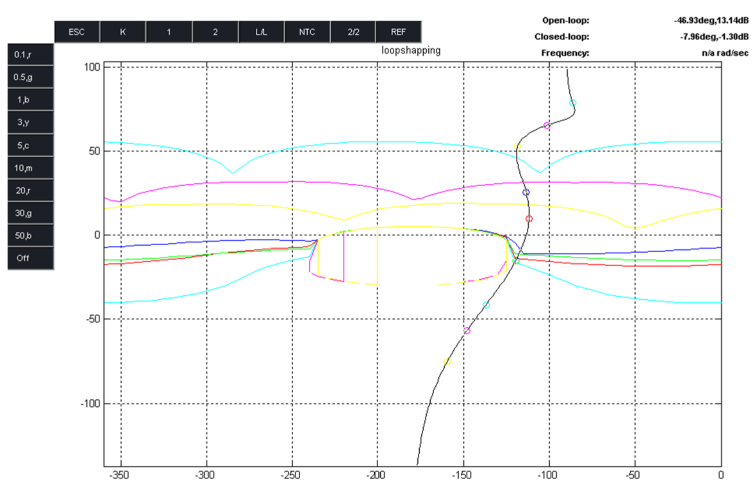


Figure 7: The controller design by loop shaping in Nichol's Chart

The desired placement of the step responses for the set of parametric combinations of the plant has to lie with the upper and lower bounds computed with the controller proceeding to the design need of a prefilter.

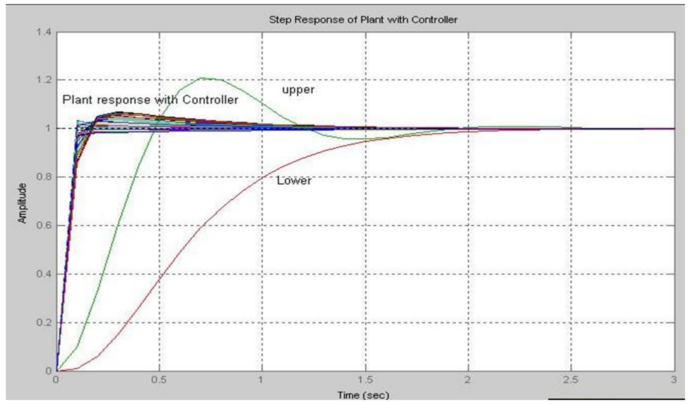


Figure 8: Step response for the plant chosen with the designed controller

Since the figure shows that the final response doesn't lie with the specific range of bounds computed, the design need of prefilter exists. And the design environment looks as follows

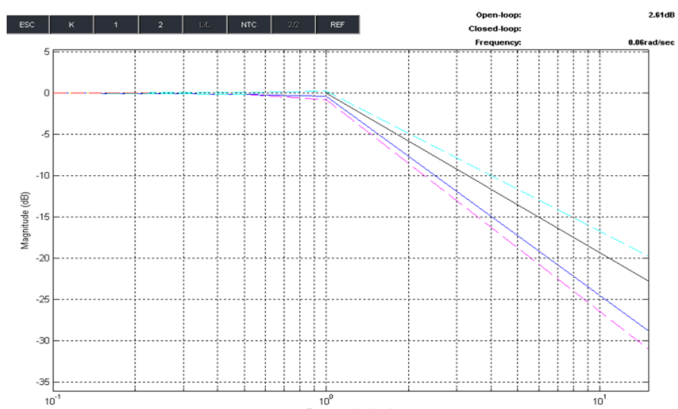


Figure 9.Prefilter design process for the nominal plant chosen

The corresponding transfer function for the prefilter is

$$F(s) = \frac{15.66}{s\,(s+2.9)(s+5.4)}$$

The relative analysis of the step response shows the design to be a satisfactory one although this deign validation has to certified with the robust stability and tracking specifications in frequency domain as well.

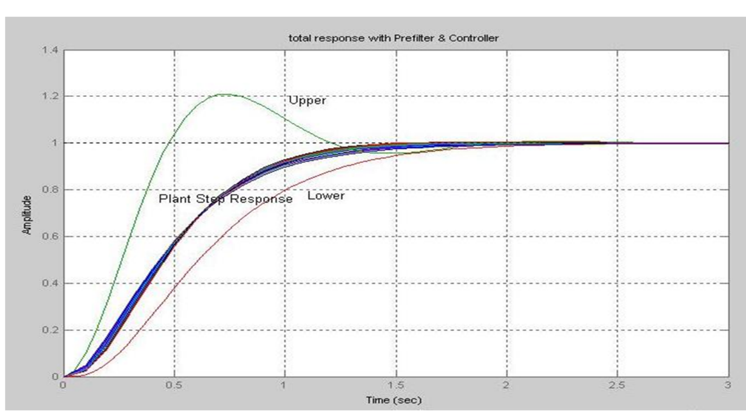


Figure 10. Closed Loop Time domain tracking response with Controller &Prefilter

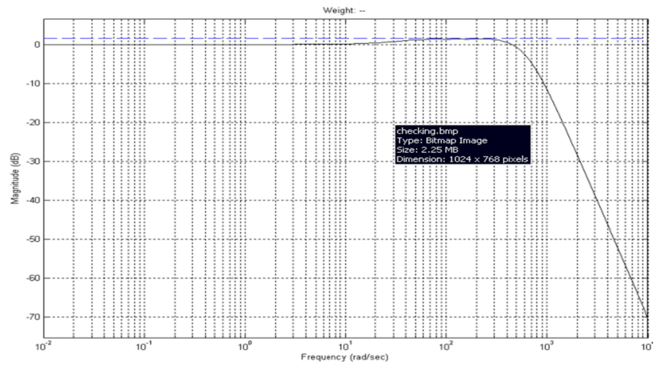


Figure 11. Analysis of Robust Stability Margins with Controller

The worst closed loop response (covering all uncertainty cases) is shown in black line, together with the design specifications plotted in the blue line. The next figure illustrates the tracking performance results where the maximum variation of the closed loop system frequency response is drawn (the area between black &blue line) together with the design specifications (the cyan & magenta line).The resultant closed loop system has met all the design specifications in the operating range.

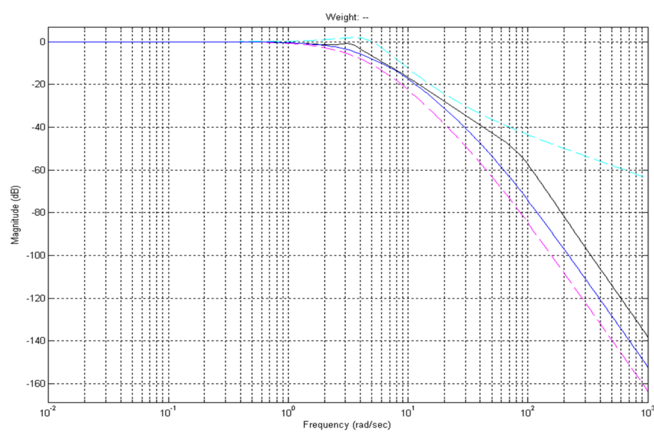
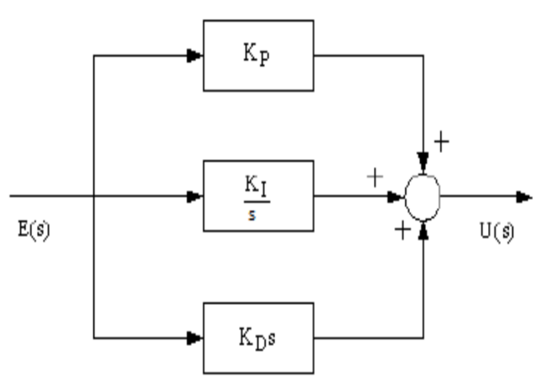


Figure 12.Analysis of Robust tracking frequency response with Controller &Prefilter

Controller desinged using PID Tuning

The conventional approach of PID tuning can be carried out similarly to obtain a sustained output for the temperature variation of the load simulator. And the resulting block diagram is as follows:



Using Ziegler Nichols method the Kp, Kd, Ki values can be found and they are as follows:Kp= 0.72, Kd=0.0045, Ki=93.6 The further placements of poles and zeroes help in adjustments for the sustained output of the plant family.

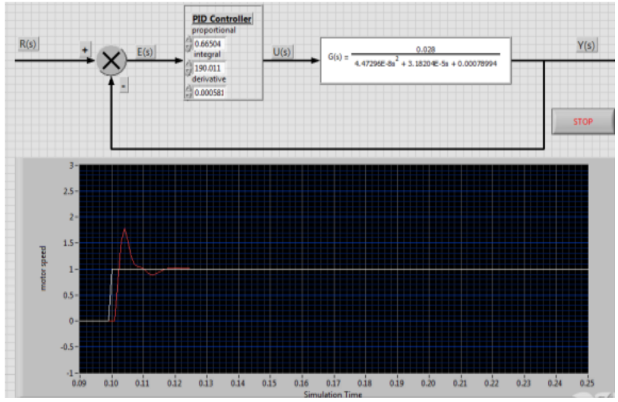


Figure 13:Simulated output for PID tuning with step input

But when the collective response of the plant could be checked with respect to QFT and PID tuning both it is observed that the performance of QFT controller is better in terms of steady state error and overshoot. Stability approaches the final value sooner in case of QFT too. But the ease of design is flexible in PID tuning. In the figure below, the green plot corresponds to the plot for QFT controller with the nominal plant and the blue line depicts the output for PID controller. The settling time is less for QFT controller and the fastness in operation in also higher than the other one too.

Some very modern techniques of bound computation like Envelope method [10] has been implemented and hence designed the controller. Relative to this design a hard ware interface can also be designed to further see the real time action of this plant simulator.

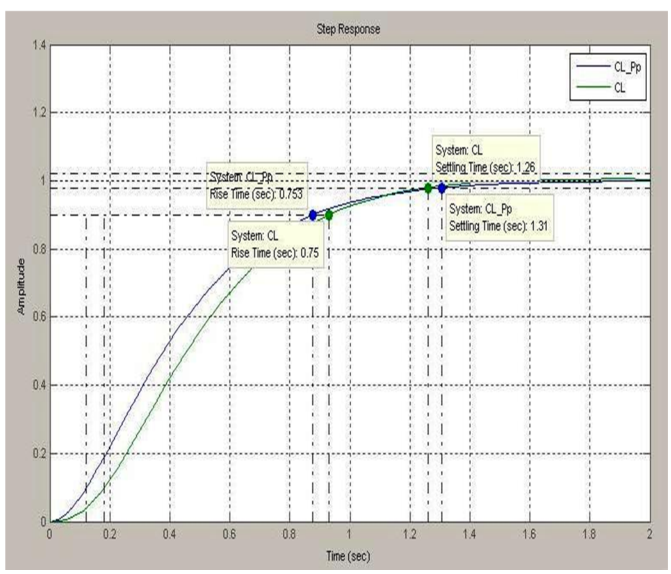


Figure 14: Comparative study of the QFT controller and PID controller.

DESIGN OF THE PLANT MODEL USING A MICROCONTROLLER

The temperature is a crucial issue for the stability and control of the system for a load simulator. A real time interface has been developed here with few counter components like: Arduino Duemilanove board, 12 V DC power Supply, LM35 sensor, BD 139 (NPN Bipolar Power Transistor), 100uF/25V capacitor, 1N4007 diode, 1k ohm resistors. The aim of this project is to design a room that reflects a comfortable living environment for human occupancy. An ideal living environment depends on primary factors that define conditions for thermal comfort such as metabolic rate, air temperature, air speed, humidity, clothing insulation, and radiant temperature. In this case we are operating under the assumption that the room is located in a tropical environment, with air temperature between a range of 10˚C - 50˚C(changeable), light clothing, and all other previously stated factors being negligible for this model.

Using this fundamental structure, the final model takes the shape of the following figure.

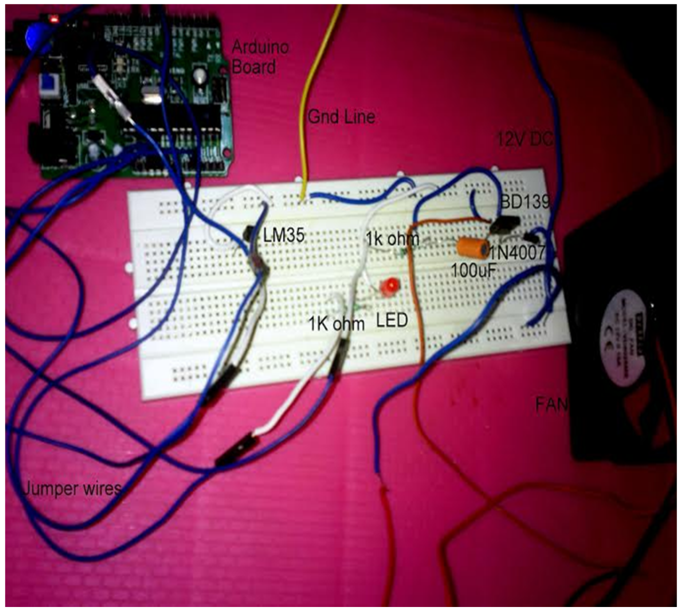


Figure 15. The laboratory made set up for controller design

In order to implement the idea of designing a controller, the microcontroller had to be fed an input from an interface of software environment and this got materialized with the help of a platform named Arduino. Arduino is an open-source electronics prototype platform based on flexible, easy-to-use hardware and software. Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling motors etc. and in this case temperature and light. The microcontroller on the board is programmed using the Arduino programming language based on wiring and the Arduino development environment based on processing. Arduino projects can be stand-alone or they can communicate with software on running on a computer.

CONCLUSION

This paper presents the relative performance index for the taken plant hydraulic load simulator with two very well known control techniques. QFT, a popular robust control technique specifies the performance of the plant with some emerging algorithms like bound computation using envelop method and horowitz-Sidi methods. Along with that the PID controller has also been designed to compare the relative betterments in function and operation. The comparative study of the two methods has also been shown. A laboratory set up has also been designed to fabricate the model of this load simulator using micro controller and not only this, this further relates an extension of interface from software to hardware design using some equipments already mentioned.

The further scope of extension of this work incorporates the implementation of newer emerging algorithms for QFT design and to optimize the parametric uncertainty for a defined problem specification to ensure best possible output.

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REFERENCES

J.W. Kim, D.J. Xuan and Y.B. Kim, "Robust control application for a three-axis load simulator," *Journal of Mechanical Science and Technology,* vol. 25, no.1, pp. 221-231, 2011J.

K.K.Ahn and Q.T. Dinh "Self-Tuning of Quantitative Feedback Theory for Force Control of an Electro-Hydraulic Test Machine," *Control Engineering Practice,* vol. 17, pp. 1291–1306, 2009.

L.I. Qiang and C. Jian, "Design of Robust Controller in Electro Hydraulic Load Simulator," in Proc. of the 5th Int. Conf. on Machine *Learning and Cybernetics*, pp. 779-784, August 2008.

D.J. Balance and G. Hughes, "A survey of Templates generation method for Quantitative Feedback Theory," *UKACC Int. Conf. on Control*, in *Proc. of IEEE*, vol. 1, pp. 172-174, 1996.

Horowitz, "Quantitative Feedback Theory," in *IEE Proc*, vol. 129, No 6, Nov. 1982.

C. Borghesani,Y. Chait, O. Yaniv, Quantitative Feedback Theory Toolbox *User's Guide*, The Math Works Inc.,Massachusetts,USA,1994.
J.J. Martín-Romero, M.G. Martínez and M. García-Sanz, "Analutical formulation to compute QFT bounds: Envelop method," *Int. Journal of Robust and Nonlinear Control*, vol. 19, pp. 1959-1971, 2009.
National Instruments, "*LabVIEW Graphical Programming*", 2011.
National Instruments, "*LabVIEW Course LV1 & LV2*", 2011.