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Design of Optimal Robust Controller for Servo Motor using Mutiobjective Optimization

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Abstract: This paper proposes design methodology for a optimal controller, posing the controller design problem as optimization problem and, then, solving it using multiobjective optimization algorithm . The objective functions for robustness and disturbance rejection are optimized using multiobjective genetic algorithm. It includes one example of optimal robust controller in PID structure for servo motor.

1. INTRODUCTION

PID controllers have found extensive industrial applications for several decades [1-3]. In the design, three PID control parameters are tuned to achieve the desired performances. The model of the plant, in general, is not accurate. This error in the model gives rise to model uncertainties. Therefore, there is need to take into account the presence of model uncertainties. The robust design techniques based on the H_∞ theory have been found to take care of the model uncertainties [4-6].

In designing optimal disturbance rejection controllers with fixed structures both tracking behavior and disturbance rejection are considered.

In last two decades, much attention has been provided to mixed H_2/H_∞ problems,[4-7] from theoretical view point. The conventional designs based on mixed H_2/H_∞ optimal control are very complicated and not easily implemented for practical industrial applications. In this paper, a design methodology for PID control is developed solving optimization problem using multiobjective genetic algorithm for global optimization.

If the conventional design based on mixed $H_2/H_\infty$for dynamic output feedback (observer based) is employed, the problem becomes that of solving four Riccati like equations [8]. Rather, this will be a complicated problem and, also, the order of controller will not be lower than the order of the plant. This design does not attract practical control engineers.

In the proposed design three unknown controller parameters are found by solving optimization problem. The optimization problems in such controller design are frequentlynonlinear,nonconvex(i.e. multimodal) and non-differentiable in nature. The methods based on the calculus would fail. The search methods can provide the solution. The search methods Like Nelder-Mead simplex search would only provide to local optimal solution. The global optimization methods are guaranteed to provide global optimal or near global optimal solution.

Roughly speaking, global optimization methods can be classified as deterministic, stochastic and hybrid strategies. Deterministic methods[9,10] can guarantee under some conditions the location of the global optimal solution. The drawback is computational effort increases with problem size and also require certain properties (like, smoothness and differentiability) of the system. Stochastic methods [11,12] are based on probabilistic algorithms and many studies have shown that these methods can locate the vicinity of the global solutions in relatively modest computational times. The hybrid strategies [12,13] try to get the best of both the worlds i.e. to combine global and local optimization methods in order to reduce their weaknesses while enhancing their strengths. The efficiency of the stochastic global methods can be increased by combining them with fast and robust local search methods.

In this paper, multiobjectiveoptimization algorithm has been used for solving optimization problem to get optimal parameters of PID controller for servomotor .

2. PROBLEM FORMULATION

Consider the control system shown in Fig.1, where $G_o(s)$ is the nominal plant and C(s,k) is the PID controller with the following form:

C(s,k)= kp+kd/s+ki (1)

Here,*k* is the vector of controller parameters:
$k = [kp, kd, ki]^T$ (2)

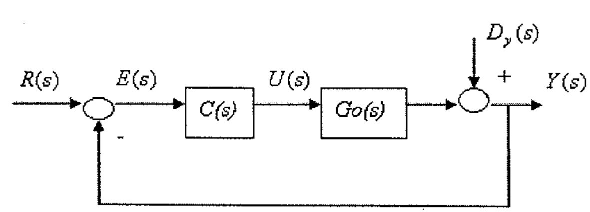

Fig.1 Control system with plant perturbation and disturbance

The Plant model, using multiplicative uncertainty is given by

$G(s)=G_o(s)[1+\Delta G(s)]$ (3)

where, $G_o(s)$ is the nominal transfer function of the plant, the plant perturbation $\Delta G(s)$ is assumed to be stable but uncertain. where the weighting function W_m is stable and known.

2.1. Objective function for stability robustness

The condition for robust stability is given as follows [4] : If the nominal control system is stable with the controller C(s,k),then the controller C(s,k) guarantees robust stability of the control system, if and only if the followIng condition is satisfied.Here, it is assumed that no unstable poles of $G_o(s)$ are cancelled in forming G(s).

Applying the defination of H_∞ norm, the robust stability condition results in the following:

$$\left\| \frac{C(s,k)G_o(s)W_m(s)}{1+C(s,k)G_o(s)} \right\|_\infty =$$

$$= \max_{\omega\in[0,\infty)} \left[\frac{C(j\omega,k)G_o(j\omega)W_m(j\omega)C(-j\omega,k)G_o(-j\omega)W_m(-j\omega)}{(1+C(j\omega,k)G_o(j\omega)(1+C(-j\omega,k)G_o(-j\omega)} \right]^{0.5}$$

$$= \max_{\omega\in[0,\infty)} (\alpha(\omega,k))^{0.5} \quad (4)$$

First objective function for robust stability in multiobjective optimization is

$$\left\| \frac{C(s,k)G_o(s)W_m(s)}{1+C(s,k)G_o(s)} \right\|_\infty = \text{f1} \quad (5)$$

2.2. Condition for disturbance rejection

Disturbance with deterministic signal form, e.g. step function, sinusoidal function, are assumed in the classical methods for controller design [4]. Taking into account disturbances using the H_∞-norm, the type of the signal can be arbitrary.

It must be assumed, however, that the amplitude of the signal is bounded. In the following, the condition for disturbance rejection will be described. Consider the control system shown in the Fig. 1 with disturbance $D_y(s)$ acting at the plant output. The controller with fixed structure is given by a rational transfer function C(s).The plant is described by its nominal transfer function $G_o(s)$.

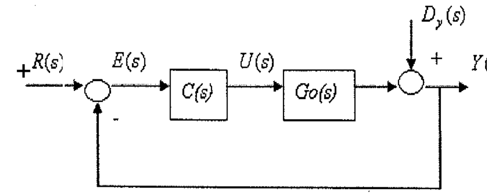

Fig.2 Control system with disturbance acting on the plant output

Let the reference signal *R(s)* = 0, then the relation of the controlled variable, Y(s), to the disturbance at the output, $D_y(s)$, can be described as follows:

$$\frac{Y(s)}{D_y(s)} = \frac{1}{1+C(s,k)G_0(s)} \quad (6)$$

The second objective function f2 for disturbance rejection in multiobjective optimization is

$$\max_{d_y(t)\in L_2} \frac{\|y\|_2}{\|d_y\|_2} = \left\| \frac{1}{1+C(s,k)G_0(s)} \right\|_\infty \quad (7)$$

3. MUTI-OBJECTIVE GENETIC ALGORITHM

Multi objective formulations are realistic models for many complex engineering optimization problems. As soon as there are many (possibly conflicting) objectives to be optimized simultaneously, there is no longer a single optimal solution but rather a whole set of possible solutions of equivalent quality [14]. A reasonable solution to a multi objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution. Being a population based approach, GA are well suited to solve multi-objective optimization problems. A generic single-objective GA can be modified to find a set of multiple non-dominated solutions in a single run. The ability of GA to simultaneously search different regions of a solution space makes it possible to find a diverse set of solutions for difficult problems with non- convex, discontinuous and multi-modal solutions spaces. The cross over operator of GA may exploit structures of good solutions with respect to different objectives to create new non-dominated solutions [15]. The goal of MOO is to find as many of these solutions as possible. If reallocation of resources cannot improve one cost without raising another cost, then the solution is Pareto optimal. A Pareto GA returns a population with many members on the Pareto front. The population is ordered based on dominance. Several different algorithms have been proposed and successfully applied to various problems such as [15]: Vector-Evaluated GA (VEGA), Multi Objective GA (MOGA), A Non-Dominated Sorting GA (NSGA) and Non-Dominated Sorting GA (NSGA II) .Multi Objective GA (MOGA) is used in the proposed research.

4. DESIGN EXAMPLE

The model of the plant, servomotor taken from [4] is described by the following transfer function:

$$G_O(s) = \frac{0.8}{s(0.5s+1)}$$

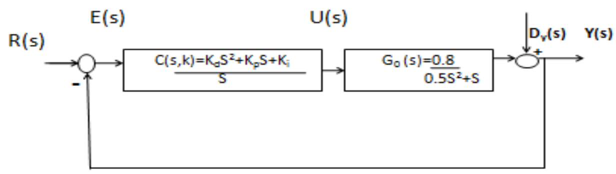

Fig.3 Control system with uncertainty and disturbance acting on the plant output

The vector k of controller parameter is given *by*

k = [kp, k_d, k_i]^T which is to be obtained solving the optimization problem. The multiplicative uncertainty $W_m(s)$ is taken a

$$W_m(s) = \frac{0.1}{s^2+0.1s+10} \quad (7)$$

First objective function for robust stability in multiobjective optimization is

$$\left\| \frac{C(s,k)G_o(s)W_m(s)}{1+C(s,k)G_o(s)} \right\|_\infty = \text{f1} \quad (8)$$

The weighing function $W_d(s)$ for disturbance rejection is taken as [4];

$$W_d = \frac{1}{s+1} \quad (9)$$

The error signal $E(s)$, assuming the input signal to be a unit step, is evaluated as follows:

$$E(s) = \frac{1}{1+C(s,k)Go(s)}R(s) \quad (10)$$

The second objective function f2 for disturbance rejection in multiobjective optimization is

f2=$\|E(s) * W_d\|_\infty$(11)

The H_∞ norm is calculated using MATLAB function normhinf.

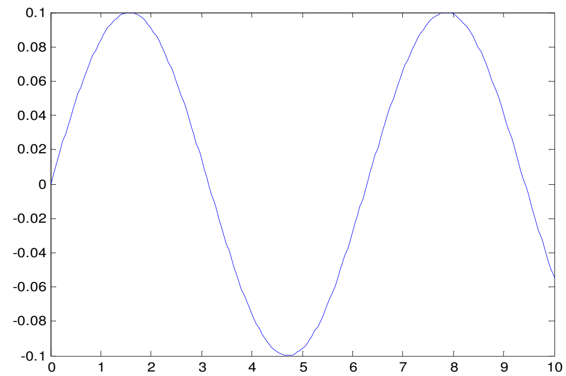

Fig.4 Disturbance acting on plant

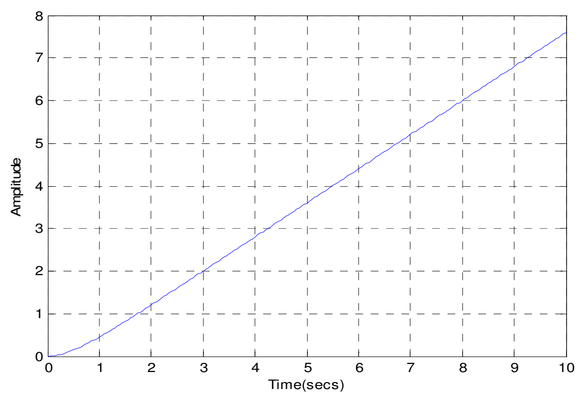

Fig.5 Step response of the plant without controller

By solving the optimizing problem following pareto fronts are obtained

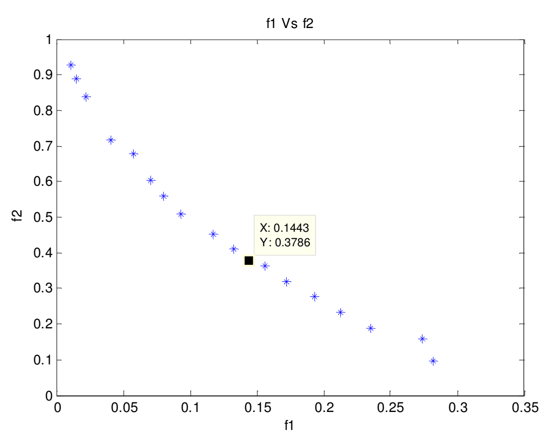

Fig.6Pareto front between fi & f2

With Optimal solution vector k1 = $[2.2822\ 1.0993\ .0491]^T$ step responses are shown in Fig.7& Fig.8

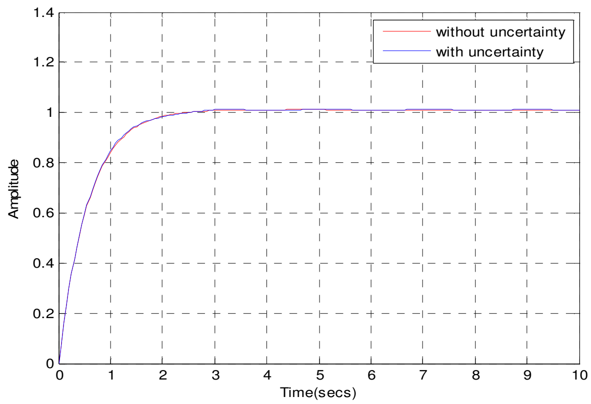

Fig.7 Step response of the controlled plant with and without uncertainty

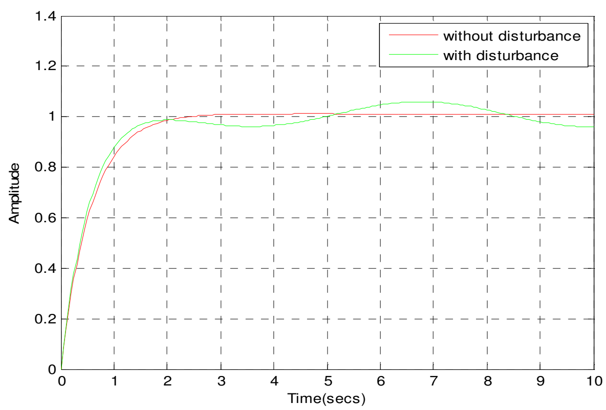

Fig.8 Step response of the controlled plant with and without disturbance

With Optimal solution vector k2 = $[6.8399\ 7.3098\ .1445]^T$ step responses are shown in Fig.9& Fig.10

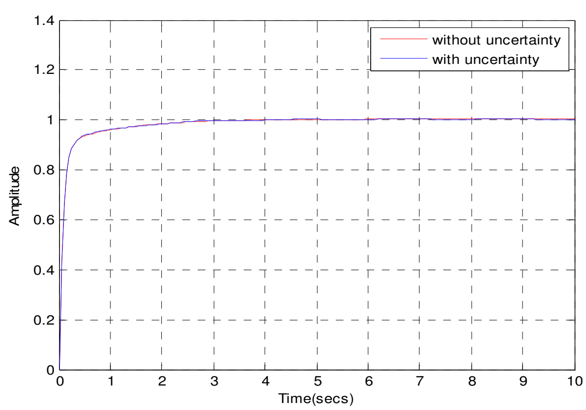

Fig.9 Step response of the controlled plant with and withoutuncertainty

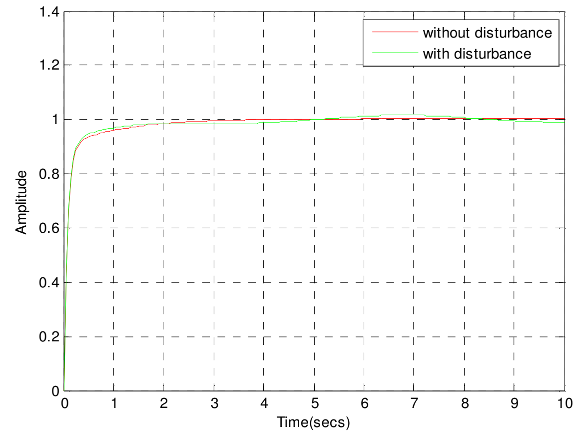

Fig.10 Step response of the controlled plant with and without disturbance

With Optimal solution vector k3 = $[2.9369\ 3.4933\ .0467]^T$ step responses are shown in Fig.11& Fig.12.

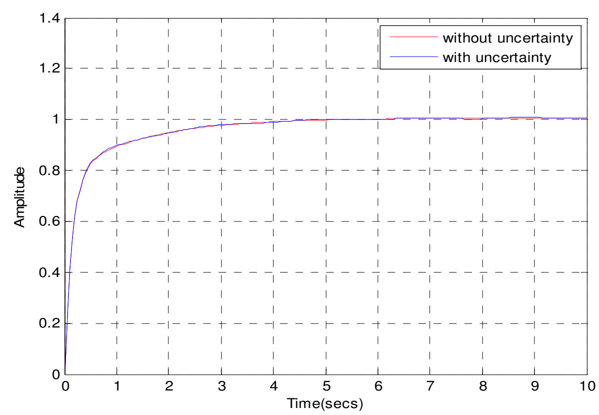

Fig.11 Step response of the controlled plant with and without uncertainty

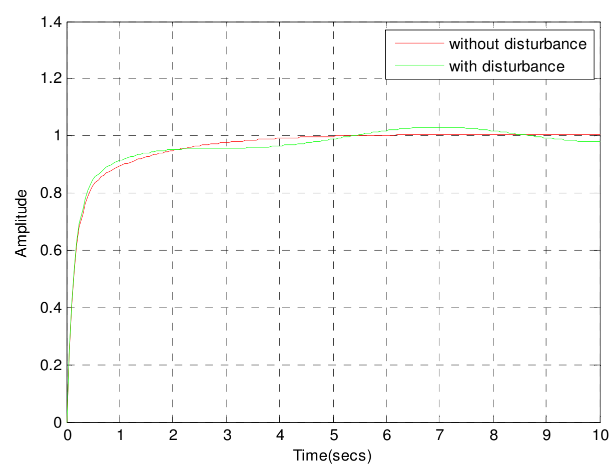

Fig.12 Step response of the controlled plant with and without disturbance

With Optimal solution vector k4 = $[6.7955\ 3.2922\ 0.1020]^T$ step responses are shown in Fig.13& Fig.14

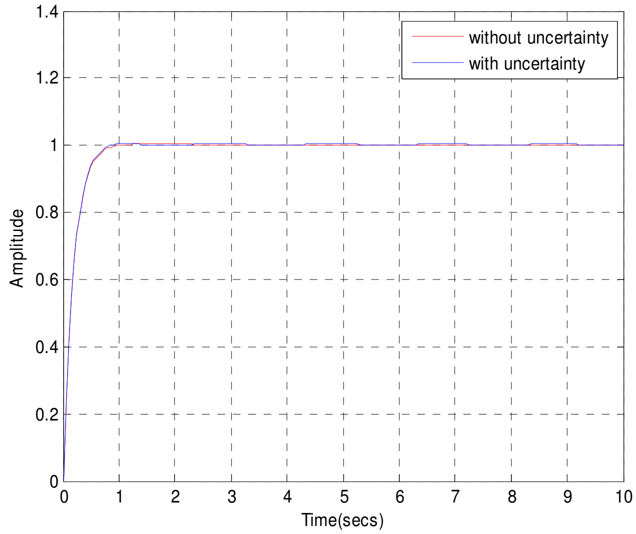

Fig.13 Step response of the controlled plant with and without uncertainty

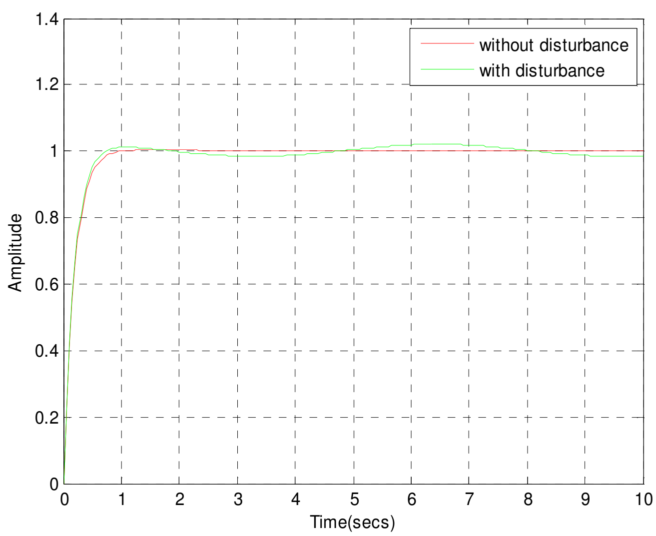

Fig. 14. Step response of the control with and without disturbance

From the above graphs it is observed that controllers with optimal solution vector k1& k3 is not rejecting disturbance properly and controller with optimal solution vector k2 has larger rise time and settling time than controller with optimal solution vector k4.

Fig.13 & Fig.14 and TABLE 1 shows that there is no difference between the two responses of k4. The designed controller gives satisfactory response in the face of plant uncertainty and disturbance.Infact there is no effect of uncertainty and disturbance on the tracking performance .

TABLE 1: The Performance of Different Controllers

S. No.	Controller	PID Parameters	Rise time	Settling time	overshoot
1.	K1	2.2822 1.0993 0.0491	1.518	1.90	1.1147
2.	K2	6.8339 7.3098 0.1445	0.7409	1.725	zero
3.	K3	2.9369 3.4933 0.0467	2.0265	3.170	0.1287
4.	K4	6.7955 3.2922 0.1020	0.5357	0.6895	0.3493

5. CONCLUSIONS

In this paper a method is presented to design an optimal robust controller with fixed structure. The objective functions for robustness and disturbance rejection are optimized using multiobjective genetic algorithm. The tracking performance of the closed loop systemfor servo motor with proposed method of k4 controller has been found superior to other controllers. Therefore the proposed control algorithms are shown to be effective. In future, this control method can be further extended to other structures and other multiobjective optimization techniques can be applied.

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