Application of Individual Channel Design to Server Control

A Rajasekar, R Devanathan

Abstract: ***There has been lately interest in the application of control theory to computing systems. Applications, such as, in cyber physical systems, demand study of the dynamic performance of computing systems under load and other disturbances. This paper addresses an important problem of feedback control of a computer server system. Considering a 2x2 server control system, individual channel design approach allows independent controller design of server utilization and average waiting time control loops. Simevents in Matlab is used to simulate, in a novel way, the physical server on which the feedback architecture is imposed. Simulation results are provided to validate the proposal of diagonal control of computer server together with demonstration of its robust performance.***

Index Terms: Feedback computing, control theory, individual channel design, discrete event system.

I. INTRODUCTION

Computing systems have been extensively analysed in terms of capacity planning under steady state operation using the principles of queuing theory [1]. However, the use of computing systems in cyber physical system has indicated the need for dynamic analysis of the computing system under load. It has been demonstrated that when a software system operates a physical system subject to external disturbances, purely algorithmic open loop software will not be valid. The execution of software will be affected by factors, such as, resource variability, system fault, or changing user priorities. In this context, IBM has proposed [2] adoption of a control paradigm introducing the monitor, analyse, plan, execute, knowledge (MAPE-K) loop. The MAPE-K loop deals with the application of control concepts into making software and computing systems self -adaptive. Mary Shaw [3], considering cruise control application, demonstrates that object-oriented software design paradigm needs to be endowed with a process control structure. Example applications of control strategies to self-adaptive software systems can be cited as fuzzy control applied to E-commerce [4], dynamically reconfigurable embedded system for energy efficient system [5] and architecture for self-repairing software systems [6]. [7] deals with the balancing of workload of computer resources across parallel systems. [8] applies feedback to solve the congestion avoidance problem. [9] applies control theory to flow control in a network using z-transform and root locus technique. [10] is concerned with the regulation of quality of service-oriented operating system schedulers employing feedback control theory. In [11], cache resource allocation problem is redefined as a controller design problem and an optimum solution under a bursty load is obtained. [12] develops a methodology to evaluate controller for software management systems. The dynamics of resource management, especially with changes in workload and configuration, require tools of control theory to address the problem. [13] fills such a need especially for computing practioners. [14] deals with the application of control design process for software systems to have desired properties and behavior. [15] discusses the response time of autonomic computing systems (that is, self-managing systems) under different control configurations.

In most of the above works, computing systems are modeled through system identification and feedback control theory is applied to the realized model. The model predictions are verified by implementing the control system on a test bed of the computing system. An earlier paper by the authors [18] has proposed a decoupling compensator for the computer server control system. This paper is concerned with the improvement of service level management of a computer server through feedback control. In particular, we show independent control of a job server outputs of Utilization and Average waiting time. The manipulated variables considered are job service time and job intergeneration time. The two server outputs are interactive and require in general the application of a 2x2 multivariable control system. Using a multivariable structure function, we choose the correct pairing of the controlled and manipulated variables of the server control system so that the two control loops are made nearly non-interactive and well established control design method of singe input and single output (SISO) system could be employed to develop a diagonal controller for the two control loops. We show that such a control is also robust for uncertainty of modeling of the server process. In terms of process modeling, we model the computer system as a discrete event system [16]. We employ 'Simevents' of Matlab to simulate the computing server directly. We impose feedback control architecture on the Simevents model using Simulink models in a novel way and study the computing server performance under control in the Simevent - Simulink environment.

The main contributions of the paper are: - (i) use of Simevents and Simulink modules for the simulation of computer server system as a discrete event system (ii) imposition of a feedback control structure on the Simevent -Simulink model (iii) identification of the server control system as a 2x2

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A Rajasekar, Department of Electronics and Communication Engineering, Hindustan Institute of Technology & Science, Chennai, India.
R Devanathan, Department of Electrical and Electronics Engineering, Hindustan Institute of Technology & Science, Chennai, India.

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interacting control system (iv) independent channel design of the 2x2 server control system and (v) simulation results to verify the performance and robustness of the proposed server control system.

The rest of the paper is organized as follows. The next section gives a brief introduction to independent channel design developed in [17]. Section 3 discusses modeling of the computer server system as a 2x2 control system using Simevents. Section 4 discusses Independent channel design of the 2x2 server control system. Section 5 discusses the simulation results on the performance of the control system. Section 6 concludes the paper.

II. BACKGROUND WORK

2.1 Individual Channel configuration

Individual channel design (ICD) is a methodology proposed in [17] for multivariable control and especially for 2x2 control. The idea of ICD is to convert the 2x2 control design problem to individual loop control design for which well-known and well-understood design and analysis techniques exist.

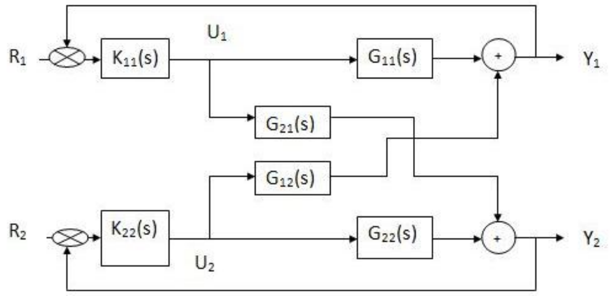

Fig.1 Conventional 2x2 control system

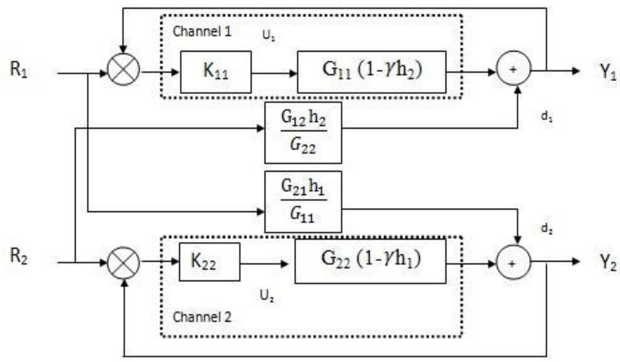

Fig.2 ICD 2x2 control system

Figure 1 shows the conventional 2x2 control system and figure 2 shows the equivalent ICD 2x2 control system [17]. The main difference between the two figures is that while figure 1 shows explicitly the dynamic interaction between loop 1 and loop 2 and vice versa, figure 2 shows the dynamically equivalent independent channels called channel 1 and channel 2. Channel 1 and channel 2include the effect of the interactive elements through the use of multivariable structure function (MSF) γ which is described below. The only interaction between channel 1 and channel 2in figure 2 is the disturbance signal arising from loop 2 reference (R_2)to loop 1 output and vice versa.

Considering figure 2, for channel 1, the forward transfer function is given by

$$C_1 = K_{11}G_{11}(1-\gamma h_2) \quad (1)$$

and for channel 2, the forward transfer function is given by

$$C_2 = K_{22}G_{22}(1-\gamma h_1) \quad (2)$$

where K_{11} and K_{22} are controllers for the loop 1 and loop 2 respectively, $G_{11,}$ and G_{22} are forward transfer functions of loop 1 and loop 2 respectively as in figure 1 and γ is themultivariable structure function (MSF) given by

$$\gamma = \frac{G_{12}G_{21}}{G_{11}G_{22}} \quad (3)$$

The closed loop transfer functions are given by

$$h_j = \frac{K_{jj}G_{jj}}{1+K_{jj}G_{jj}}, \text{ j = 1,2.} \quad (4)$$

2.2 Individual channel design (ICD)

Since C1 and C2 employ the interactive factor $(1-\gamma h_1)$ and$(1-\gamma h_2)$ respectively, an additional zero is created by the factor$(1-\gamma h_j)$, j = 1, 2. If (γh_{jj}), j = 1, 2 is close to 1, there will be a great interaction between loop1to loop 2 and vice versa. In order to keep the interaction low, the Nyquist plot of (γh_j), j = 1, 2 has to be as far removed as possible from the (1, 0) point. It follows from (4) that $|h_j| \leq 1$, j=1, 2 for positive controller gains $K_{jj,}$ j = 1, 2. Hence, $|\gamma| \ll 1$ results in low interaction between the loops.

Given two controlled variables and two manipulated variables, we can always get two different pairs of controlled and manipulated variable combinations. It follows that MSF γ for each of the pairing is inverse of the other. If for the given pairing, $|\gamma| \gg 1$, then the alternate pairing can be assumed in which case$|\gamma| \ll 1$.In the latter case, with the minimal interaction between the two loops, the controller for the loops can be individually designed based on the well-known Single input and single output (SISO) methods involving gain and phase margins thus resulting in a diagonal controller.

2.3 Robust Design

It is shown below that when$|\gamma h_j| \ll 1$, j=1,2 on the Nyquist plot, then good phase and gain margins of the individual loops can be shown to correspond to good robust designs for loop 1 with the uncertainty of transfer function in loop2 and vice versa.

Proposition 1

(i) A sufficient condition for robust design of a loop in a 2x2 control system in respect of uncertainty in the plant transfer function of the interacting loop and vice versa is that $|\gamma h_j| \ll 1, j = 1,2$

(ii) Given that the controller gains $K_{jj,}$ j=1,2are positive and sufficiently small, a sufficient condition for robust design of (i) is that$|\gamma| < 1$.

III. SERVER SIMULATION

The server system is simulated using Simevents module of Matlab which allows the server to be modelled directly in terms of a discrete event

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system. Figure 3 shows the simulation configuration of a computer server control system using Simevents and Simulink modules. Forming feedback loops around the server variables involves time based modules such as the controller block and the delay block. In figure 3, time based entity generator block is connected to attribute block. The time based entity block generates jobs as per Poisson process with rate λ and the intergeneration time is denoted as IGT. The attribute block enables the service time (ST) of the server to be changed. The attribute block feeds into the queuing block where the tasks are queued as per First In First Out scheme. The queue block is connected to the single server block. Parameters output from the server are utilization (UT) and average waiting time (AWT). The utilization is fed back through controller block to service time input of the attribute block. The average waiting time (AWT) is fed back through a controller to the Time based entity generator. To include the continuous blocks under Simevents simulation, time to event and event to time blocks are inserted as necessary. Simevents models are meant for open loop configuration and hence formation of feedback loop results in algebraic loop error. To avoid algebraic loop error, a delay block is added in each of the loops. To make control signal bipolar, a fixed bias in the control signal is used in both the UT and AWT loops. However, since the bias inputs are constants, they are not taken into account in the dynamic analysis. Figure 3 assumes pairing of controlled and manipulated variables as UT- ST respectively in one loop and as AWT-IGT respectively in the other loop as is justified below.

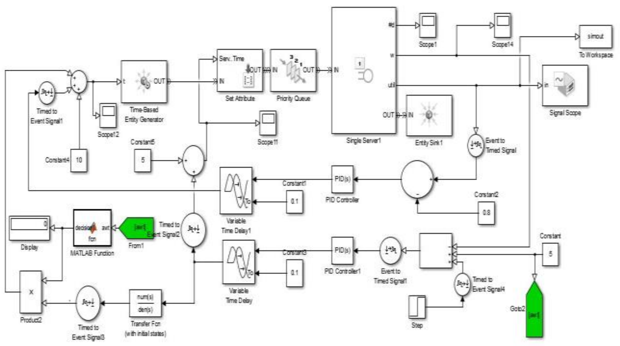

Fig.3 Simulation of computer server control

IV. SYSTEM ANALYSIS

4.1 Identification& Pairing

Consider a 2x2 model of the server as shown in figure 4.

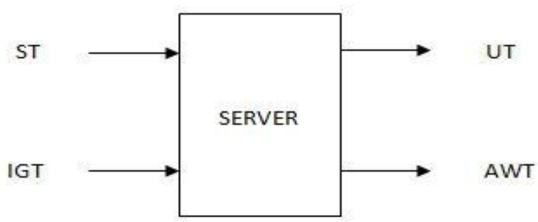

Fig.4 2x2 control model

In figure 4, ST denotes Service Time, IGT denotes Inter Generation Time, UT denotes Utilization Time, and AWT denotes Average Wait Time. System Identification is carried out on the server variables using Matlab on the Simevent model described earlier. The settings used are UT = 0.5 and AWT = 5. The transfer functions identified are given below.

$$G_{11}\ (ST - UT) = \frac{2.522s + 0.001746}{s^2 + 12.61s + 0.00873} \quad (5)$$

$$G_{21}\ (ST - AWT) = \frac{13.55s + 0.02113}{s^2 + 13.55s + 0.2113} \quad (6)$$

$$G_{12}\ (IGT - UT) = \frac{29.09s + 0.02347}{s^2 + 14.55s + 0.01173} \quad (7)$$

$$G_{22}\ (IGT - AWT) = \frac{135.4s + 0.1088}{s^2 + 13.54s + 0.01088} \quad (8)$$

Considering the pairing of manipulated and controlled variables respectively as follows,

(i) IGT –UT and ST – AWT

$$\gamma = \frac{G_{IGT-AWT}\, G_{ST-UT}}{G_{IGT-UT}\, G_{ST-AWT}} \quad (9)$$

Considering the alternate pairing of manipulated and controlled variables respectively as

(ii) ST –UT and IGT – AWT

$$\gamma = \frac{G_{IGT-UT}\, G_{ST-AWT}}{G_{IGT-AWT}\, G_{ST-UT}} \quad (10)$$

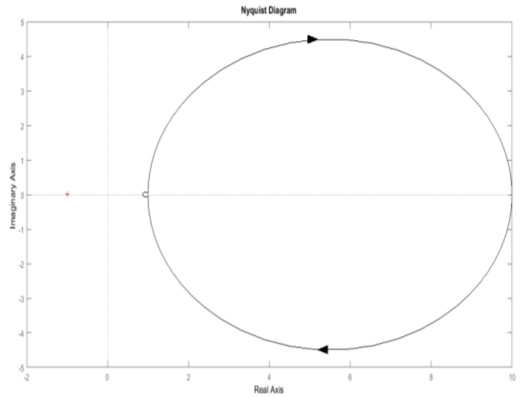

Fig.5(a) Nyquist plot of γ case (i)

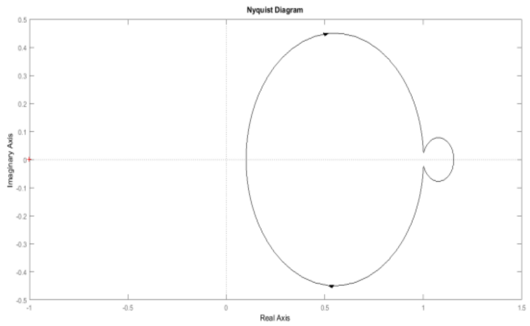

Fig.5(b) Nyquist plot of γ case (ii)

Nyquist plots of γ for cases (i) and (ii) are shown in figure5. Comparing figure 5(a) and 5(b), the pairing in case (ii) of ST –UT and IGT – AWT is preferred because $|\gamma|$ranges from 0.1 to 1 (nearly except for a range of frequency near infinity) compared to the range of 1 to 10 for $|\gamma|$ in case (i). As per Proposition 1 (ii), the pairing of case (ii) is preferred and is assumed hereafter. Hence we assign c1 as UT, u1 as ST and c2 as AWT, u2 as IGT as shown in figure 6.

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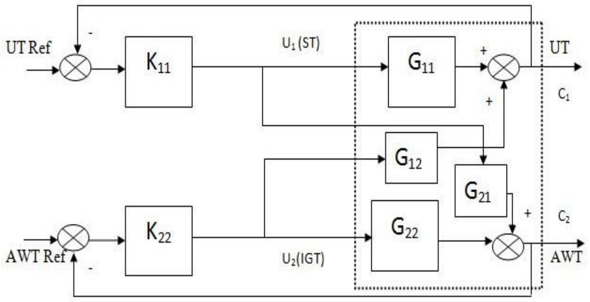

Fig.6 Server 2x2 Control

4.2 Control System Design

From figure 1,

$$h_1 = \frac{K_{11}\, G_{11}}{1+K_{11}\, G_{11}} \qquad (11)$$

$$h_2 = \frac{K_{22}\, G_{22}}{1+K_{22}\, G_{22}} \qquad (12)$$

With positive gain values of controller K_{11} and K_{22}, as per (4),

$|h_1| \le 1$,

$|h_2| \le 1$,

By tuning K_{11} and K_{22}, such that $|h_j| \ll 1$, j=1, 2.we can keep $|\gamma h_j| \ll 1$,$j = 1{,}2$ thus satisfying Proposition 1 (i) requirement for robust design.

Starting from $K_{11} = K_{22} = 1/s$, we iteratively tune the two controllers. The integral control is assumed for K_{11} and K_{22} since the steady state error for a step input is required to be zero. The tuned controllers are $K_{11} = 0.02/s$; $K_{22} = 0.0005/s$. Nyquist plots of γh_1 and γh_2 are shown in figure 7(a) and 7(b) respectively.

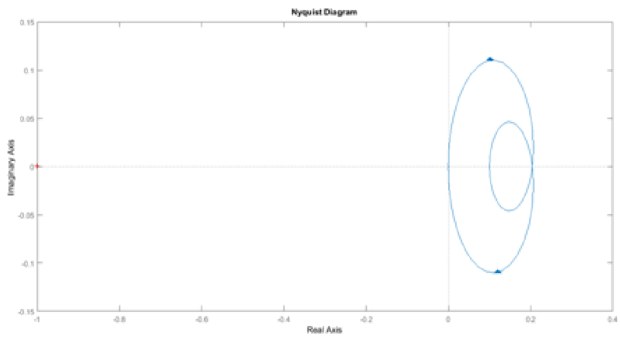

Fig.7(a) Nyquist plot of γh_1

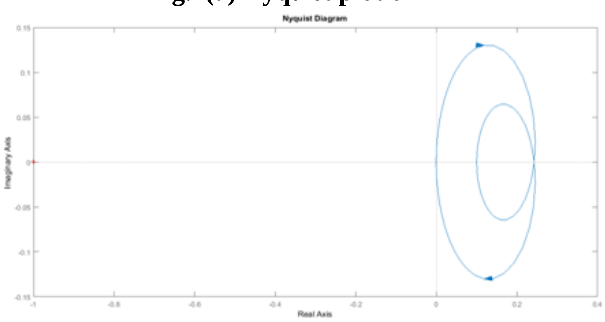

Fig.7(b) Nyquist plot of γh_2

Clearly as seen from the figure 7(a) and 7 (b), the Nyquist plot of γh_1 and γh_2 are far removed from (1, 0). Hence the interaction between the two loops will be minimal.

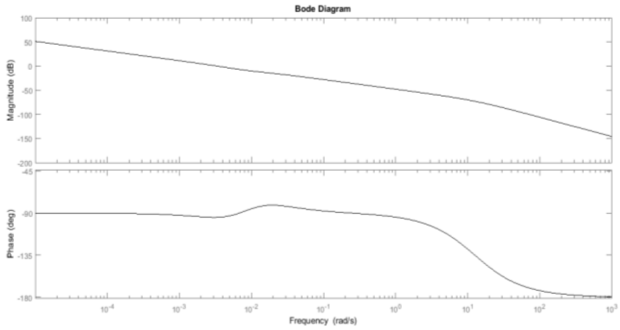

Fig.8(a) Bode Plot of Channel 1

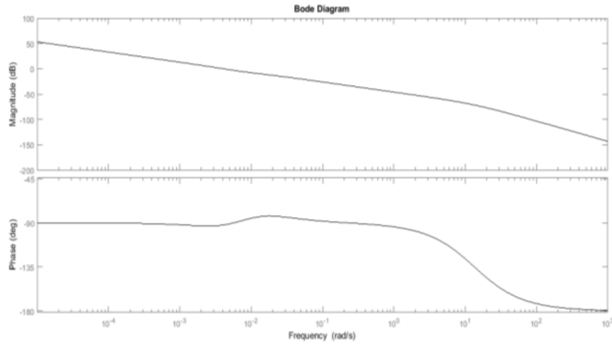

Fig.8(b) Bode Plot of Channel 2

Figure 8(a) and 8(b) give the Bode plot of channel 1 (C1) and channel 2 (C2) respectively. The gain cross over frequency ω_c and 3dB loop bandwidth ω_b are read from the graph as given in Table.1.The stability margins of the two loops are satisfactory as shown in Table 1.

Table.1 Stability Margin

Channel	C_1	C_2
Gain cross over (ω_c) (rad/sec)	0.0032	0.0039
Loop Bandwidth(ω_b)(rad/sec)	0.0045	0.0056
Phase Margin(deg)	86°	89°
Gain Margin(dB)	∞	∞

V. SIMULATION TEST RESULTS

5.1 Set point and disturbance response

Figure 9(a) and 9(b) give the plots of set point response of loop 1 and loop 2 for reference shift from 0.2to 0.5 and from 3 to 5 respectively.

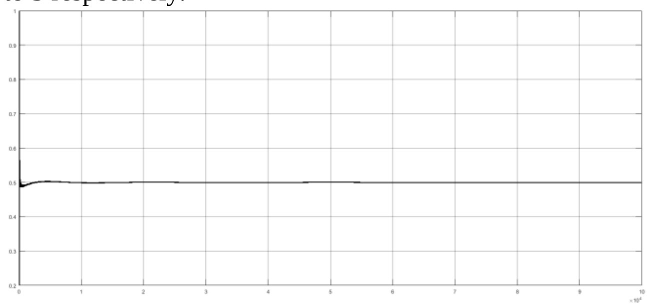

Fig.9(a) Utilization Set point Response from 0.2 to 0.5

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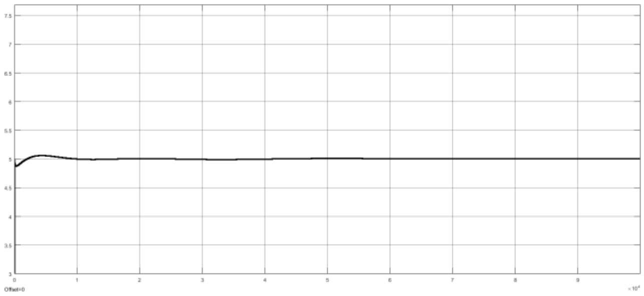

Fig.9(b) Average Wait Time Set point Response from 3 to 5

Loop interaction

To check the interaction between the loops, we changed the set point of loop 2 (AWT loop) and noted the output response of loop 1 (UT loop) and vice versa. Figure 10(a) and 10(b) give the disturbance response of loop 1 and loop 2 respectively for set point change at time t = 10000 in the other loop.

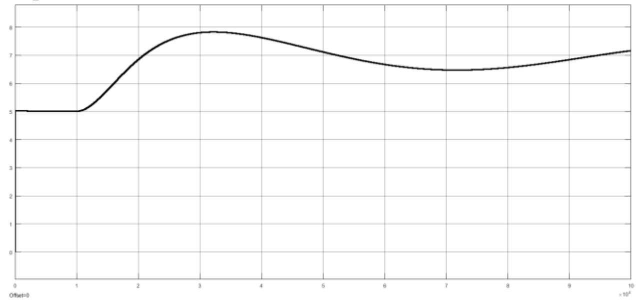

Fig.10(a) (i) Average Wait Time Set point change at t = 10000

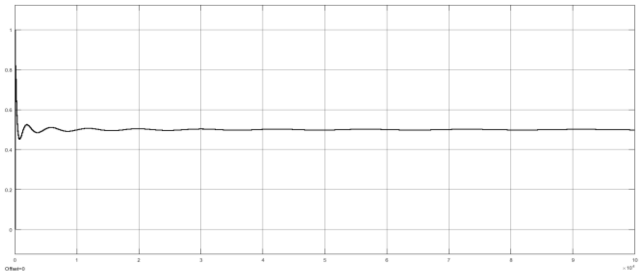

Fig.10(a) (ii) UT loop response for AWT change at 10000asin 10 (a) (i)

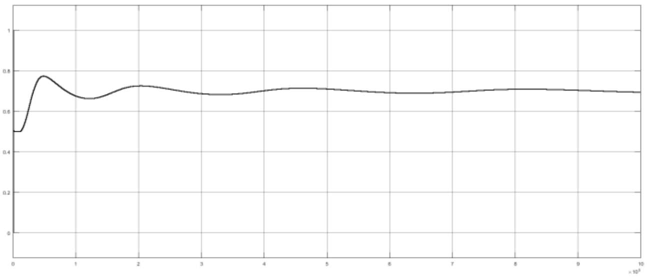

Fig.10(b) (i) Utilization step change at t = 10000

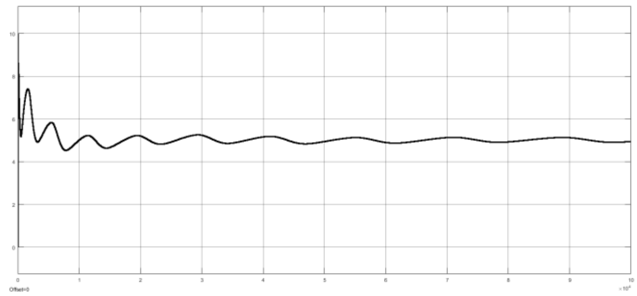

Fig.10(b) (ii) AWT loop response for UT change at = 10000 as in 10(b) (i)

Robustness

Considering 10 % change in the gain of G_{22}, at t = 60000 we get the response in loop 1 which is utilization loop and with a10 % change at t= 60000 in the gain of G_{11} we monitor the response in loop 2 (AWT loop) as shown in figure 11(a) and 11(b) respectively. It is seen from figures 11(a) and 11(b) that 10% uncertainty in the open loop transfer function of one loop does not affect the response of the other loop and vice versa thus demonstrating robustness property.

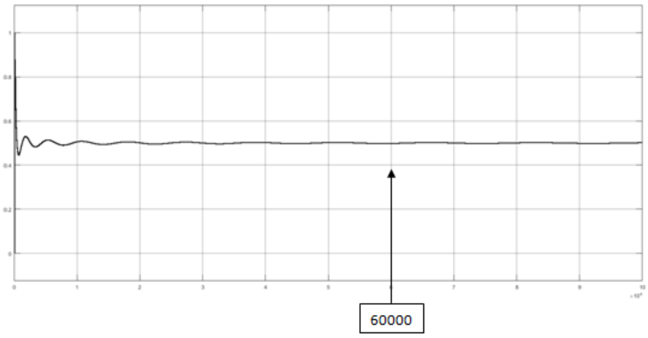

Fig.11(a) Utilization response for10 % change in the gain of G22

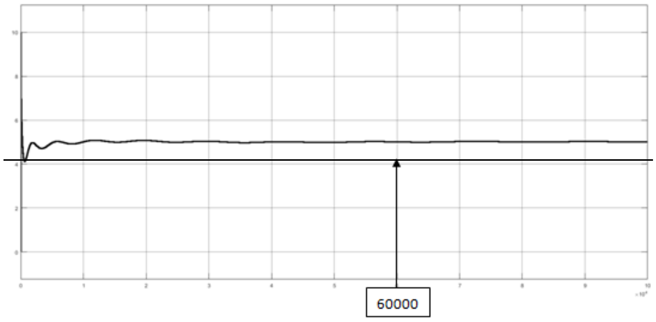

Figure 11(b) AWT response for 10 % change in the gain of G11

VI. CONCLUSION

Feedback computing is an emerging area where the dynamic response of a computing system under feedback control is studied. In this paper, computer server control is modelled as a 2x2 control system. Multivariable structure function is selected to minimize the interaction between the two server control loops. Using the concept of Independent channel design (ICD), the two server loops are individually designed through an interactive technique. Using Simevents, the computer server under feedback control is simulated in a novel way. Simulation results show that the ICD approach provides a robust design of the server control system under uncertainty of the loop transfer function in spite of a simple diagonal controller used. As a computer server cannot be modelled accurately, a model free design of server control system will be useful. This constitutes our future work.

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