

ULAB JOURNAL OF SCIENCE AND ENGINEERING

A RESEARCH PUBLICATION OF ULAB

November 2013

Vol. 4

ISSN: 2079-4398

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ULAB JOURNAL OF SCIENCE AND ENGINEERING

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Editorial

Vol. 4, 2013

WE are pleased to present the fourth volume of the ULAB's Journal of Science and Engineering (JSE). It's been another successful year for us. Since 2010, ULAB's JSE has maintained its position as the most prestigious national publication in the field of science and engineering. We feel proud that the journal has crossed the national boundary and becomes international. Now we are getting papers from abroad.

In 2010 (first volume), 28 papers were submitted for publication, with 10 being accepted (acceptance rate: 35.71%). In 2011 (second volume), submissions increased to 30 and after peer review 10 papers were being accepted (acceptance rate: 33.33%). In 2012 (third volume) 17 (including 1 from UK) papers were submitted for publication, with 9 being accepted (acceptance rate: 52.94%). In the first volume, we found many ordinary papers were being submitted, but the quality of submitted paper is gradually improving in the subsequent volumes. This year we have received 16 submissions (including 3 from India and 1 from South Korea) and after peer-review 8 are being accepted (acceptance rate: 50.00%).

According to the publication policy all papers submitted to this journal have been subject to a rigorous peer-review. We continuously strive to publish original research that contains elements with technical novelty in a timely manner. The journal's focus is on traditional areas of both theoretical and practical applications of physics, mathematics, statistics, environmental science, electronics, computer science, information and communication engineering. In addition, we shall gladly accept submissions on emerging technologies and other emerging areas related to the above fields.

You are most welcome to read this issue of the ULAB Journal of Science and Engineering. In order to continue publishing a high-quality journal, JSE's editorial board seeks excellent contributions containing original research or reviews. Our editorial board works tirelessly to provide contributors with a prompt and thorough review process.

We would like to extend our heartfelt thanks to every author, reviewer and reader for your support and dedication to JSE. We strongly believe that together, we shall elevate the journal to even higher levels of quality, impact, and reputation.

Mohammad Shorif Uddin
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Cluster Synchrony Dynamics in Coupled Neuronal Bursters

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Abstract—Emergence of partial synchrony in the activity patterns among neurons in a coupled system is crucial for functional neuronal networks. In this paper, we report emergence of spontaneous synchrony clusters in the coupled Hindmarsh-Rose neuronal bursting system with a cubic coupling. Detailed numerical analysis and simulation for three-Hindmarsh-Rose burster system show that the bursting neurons organize into separate burst synchrony clusters. A similar burst synchrony dynamics is also observed in the larger network of bursting neurons. Moreover, developing a variational system about the clustered solution for three-burster system, we compute the Lyapunov exponents of the system in order to explore the stability dynamics of the emergent burst synchrony cluster.

Keywords—Bursting rhythm, clustered synchrony, Lyapunov stability, neurons, nonlinear dynamics, variational systems.

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Manuscript received on 14 September 2013 and accepted for publication on 27 October 2013.

1 INTRODUCTION

DURING neuronal bursting, the slow currents drive the fast subsystem through bifurcations of equilibria and limit cycles that generate an activity pattern consisted of a relatively slow rhythmic alternation between an active phase of rapid spiking and a quiescent phase without spiking. Bursting is a multiple time scale phenomenon. To understand the dynamics of bursting, it is assumed that the fast and slow currents of the bursting cells have different time scales [1]–[6]. Bursting is exhibited by a wide range of nerve and endocrine cells, including pancreatic β -cells [7]–[10], respiratory pacemaker neurons in the pre-Botzinger complex [11], dopaminergic neurons of the mammalian midbrain [12], thalamic relay cells [13], [14], stomatogastric ganglion neurons in lobster [15], Aplysia abdominal ganglion neuron R15 [16]–[20], some mesencephalic V neurons in brainstem, and pyramidal neurons in the neocortex [21]. While the synchrony properties of the regular spiking neurons are well understood, the synchronization involving the multi-timescale bursting activities of the coupled neuronal system is very much an active area of research interest in both theoretical and biological neuroscience [22].

In this paper, we study the burst synchrony properties of a mathematical bursting model known as Hindmarsh-Rose model [23], [24], [25], [26]. It is understood that the rhythm generator of the leech heart interneuron can show interesting burst synchrony patterns where neurons from one side fire inphase burst while neurons from either side fire antiphase bursts; this generates rhythmic activity at about 0.1 Hz that paces leech heart neurons that in turn drives the heart beat [27], [28]. This pattern has been a subject of mathematical investigation by many authors

recently, particularly we refer to [28] where a three-cell network of conductance-based model was studied to capture and understand such leech heart interneuron burst synchrony pattern. In this paper we pursue a more mathematical interest in the rhythmicity involving burst synchronization generated by a network of three-Hindmarsh-Rose burster coupled with a cubic nonlinear coupling. The system demonstrates spontaneous cluster burst synchrony patterns where two cells fire inphase bursts while the third remains antiphase; we refer to this behaviour as ‘burst synchrony cluster’. We also observe switching between available cluster states depending on the input parameter of the system. We carry out a Lyapunov stability analysis of the emergent cluster states. We also demonstrate an example of emergence of more complex spontaneous burst synchrony cluster in network of high-dimensional system.

The paper is organized as follows. Section 2 deals with the mathematical model and the dynamics of the Hindmarsh-Rose bursting followed by a general mathematical formalism of the nonlinearly coupled system of bursters. A detailed numerical result is demonstrated in Section 3. In Section 4, variational method is used for computing Lyapunov exponents to explore the dynamical stability of the cluster system. Section 5 gives a brief numerical result of larger network. Finally, conclusion and future outlooks are summarized in Section 6.

2 MATHEMATICAL MODEL

2.1 Hindmarsh-Rose Bursting

The Hindmarsh-Rose neuronal bursting model [23], [24], [25] is given by differentialequations:

$$\begin{aligned}
 \dot{x} &= y - ax^3 + bx^2 - z + I \\
 \dot{y} &= c - dx^2 - y \\
 \dot{z} &= r(s(x - x_0) - z)
 \end{aligned} \tag{1}$$

Here the notations for the state variables (x, y, z) and other parameters are used as in [24]. Evidently the Hindmarsh-Rose system (1) generates slow-fast oscillations; the first two equations govern spiking while the third equation with a slow time scale r accounts for the bursting and adaptation. The value of r is usually assumed very small ($r \ll 1$) in order to separate the fast xy -subsystem from the slow z -subsystem. The other parameters of the system are interpreted as following: I is the input current injected into the cell, the qualitative aspects of the system are governed by the parameter b , such as

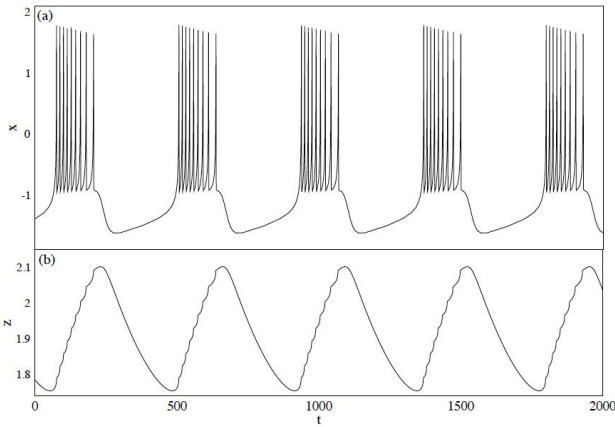


Figure 1: The bursting pattern generated by Hindmarsh-Rose system (1). The burst activity patterns are shown in (a), and the corresponding slow variable z is in (b).

bursting or spiking can be induced by changing it. x_0 is the resting potential of the system and s tunes the adaptation of the system so that the small s (values around one) yields fast spiking behaviour.

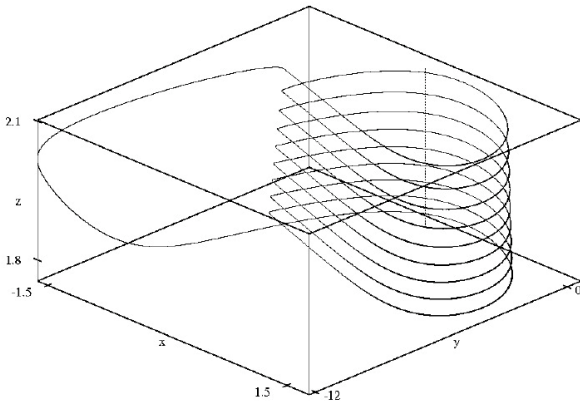


Figure 2: The 3D phase-space structure of Hindmarsh-Rose system (1) in the bursting region.

In case of bursting, decreasing time scale r can result in increasing number of spikes per burst. Fig.1 demonstrates the bursting pattern generated by the Hindmarsh-Rose

system (1); panel (a) shows the square-wave bursting patterns and panel (b) shows the timeseries of the corresponding slow variable z . A 3-dimensional phase space realization for the Hindmarsh-Rose bursters is shown in Fig. 2. The small time scale parameter r allows the usual adiabatic approach to studying the fast subsystem with the slow variable as a parameter. Fig. 3 is the bifurcation diagram of the system (1) obtained by applying slow-fast decomposition method (Section 1.3). The stable and unstable steady states are indicated by SSS (thin solid) and USS (dash-dotted) lines, respectively; SP indicates the stable periodic solutions: the upper branch is the maxima and the lower branch the minima of the solutions. The corresponding two-dimensional ‘hedgehog’ trajectory of the bursting solution is superimposed to show its position in the phase space and the solid arrows around it shows the direction of the evolution of the trajectory in the phase space. This bifurcation diagram is obtained with XPPAUT [29]. Note the onset of the burst occurs via a ‘fold’ bifurcation (indicated by ‘F’) and the offset of the burst occurs via a homoclinic (‘H’) bifurcation. One interesting feature is the existence of bifurcation delay in both onset and offset of the burst and they are indicated by broken arrows. Because of the homoclinic bifurcation at the offset of the burst where the system changes from spiking to quiescent state, the period of the spikes at the end of the burst get infinite which is reflected in the increased interspike spacing in the spikes towards the end of the burst (see Fig. 1(a)).

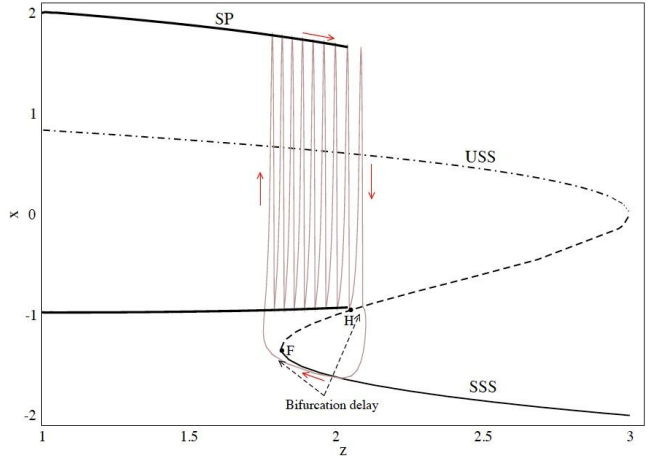


Figure 3: The bifurcation diagram of the Hindmarsh-Rose system (1). The bursting trajectory is superimposed on the bifurcation diagram to show the bursting solutions in the phase space. The stable steady state (SSS) solutions are shown with thin solid line while unstable steady state (USS) solutions are shown by dash-dotted line. SP indicates the stable periodic branch of the solution.

2.2 Coupled Hindmarsh-Rose Bursters

The general form for n -Hindmarsh-Rose cell with voltage-dependent coupling may be written as

$$\begin{aligned}
 \dot{x}_j &= y_j - ax_j^3 + bx_j^2 - z_j + I + G_k(x_1, x_2, \dots, x_n) \\
 \dot{y}_j &= c - dx_j^2 - y_j \\
 \dot{z}_j &= r(s(x_j - x_0) - z_j)
 \end{aligned} \tag{2}$$

where $G_k(x_1, \dots, x_n)$ represents the dimensionless current

flowing into the j th cell when all voltages are as specified. In neural systems it is reasonable to look at pairwise coupling only, where the current is a sum of the currents for each connection, in which case we have

$$\begin{aligned}\dot{x}_j &= y_j - ax_j^3 + bx_j^2 - z_j + I + \sum_{k=1}^n h(x_j, x_k) \\ \dot{y}_j &= c - dx_j^2 - y_j \\ \dot{z}_j &= r(s(x_j - x_0) - z_j).\end{aligned}\quad (3)$$

In this study we consider an arbitrary polynomial coupling function $h(x_j, x_k)$ difference of the action potential which is given as

$$h(x_j, x_k) = \sum_{p=1}^m c_{jk} \kappa_p (x_k - x_j)^p \quad (4)$$

with the coefficients κ_p representing the coupling strength of order p where $p = 1, \dots, m$; c_{jk} is the connectivity matrix. The coupling given by (4) may be considered as an approximation of the nonlinear synaptic coupling and the lowest order with $p = 1$ reduces it to linear diffusive electric coupling. In this study we consider $c_{jk} = 1$ and $c_{jj} = 0$ implying all-to-all coupling and no self-coupling, respectively, and we truncate the coupling polynomial up to cubic terms, i.e., $m = 3$; in this chapter we only study the system with cubic polynomial coupling function. Additionally, as regards to the coupling strength we consider $\kappa_1 = \kappa_2 = \dots = \kappa$ for simplicity.

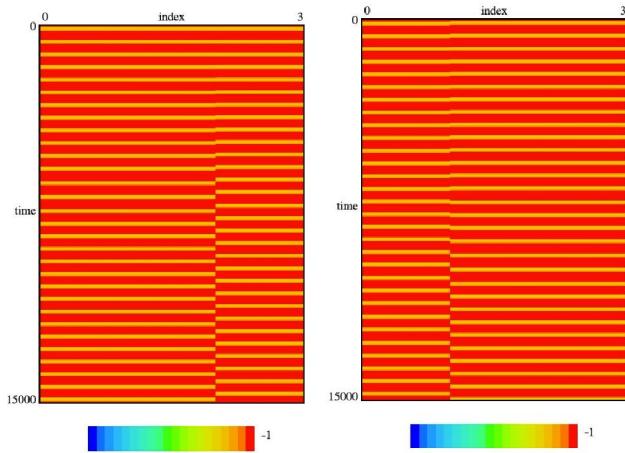


Figure 4: Array diagrams demonstrating 2-1 (left) and 1-2 (right) burst synchrony cluster states governed by the Hindmarsh-Rose system (3) and (4).

3 THREE-COUPLED BURSTING SYSTEM

3.1 Burst Synchrony Clusters

In this section we present results of simulation of a coupled system consisting of mutually inhibitory three Hindmarsh-Rose neurons ($n = 3$) governed by (3) and (4). All the coupling coefficients are same given by $\kappa_p = \kappa$ where $p = 1, \dots, m$. Fig. 4 summarizes the simulation results for the study in the form of array diagrams. In the

arrays the intensity of the voltage variables x_1 , x_2 and x_3 have been encoded in colour spectrum. The far right red part of the spectrum indicates the higher values for the voltage variables, consequently, the red lines in the array imply the burst activity while the yellow part of the array implies the quiescent activity of the burst where the voltage variables have relatively lower values. The vertical line of the array shows the time with increasing downward and the three bursters shown along the horizontal line that should equally divide the horizontal line. These diagrams were obtained from the simulation of the coupled system in XPPAUT [29]. The diagrams were obtained from similar system but with different initial conditions. The parameters for both realizations are $a = 1$, $b = 3$, $c = 1$, $d = 5$, $x_0 = -1.6$, $r = 0.001$ and $s = 4$; for both the input parameter $I = 3.0$ and the coupling strength $\kappa = -0.001$. It can be observed that the bursters start of inphase and then separate into two burst synchrony clusters: (top) 2-1 cluster state where the first two cells fire synchronous bursts while the third burst gets antiphase, (bottom) 1-2 cluster state where the first cell fires antiphase bursts to the second and third cells and this is symmetric to the result shown in top. We observe from extensive simulation that the spontaneous burst synchrony clusters are harder to obtain in the system with linear coupling. Additionally, excitatory coupling or $\kappa > 0$ results in inphase bursts.

Fig. 5 shows the changing of burst synchrony cluster states for three Hindmarsh-Rose neurons governed by the system (3) and (4) with $n = 3$ depending on input I . For all cases the initial conditions are same; the system parameters are same and they are as in Fig. 1 for each cell and the coupling strength $\kappa = -0.001$.

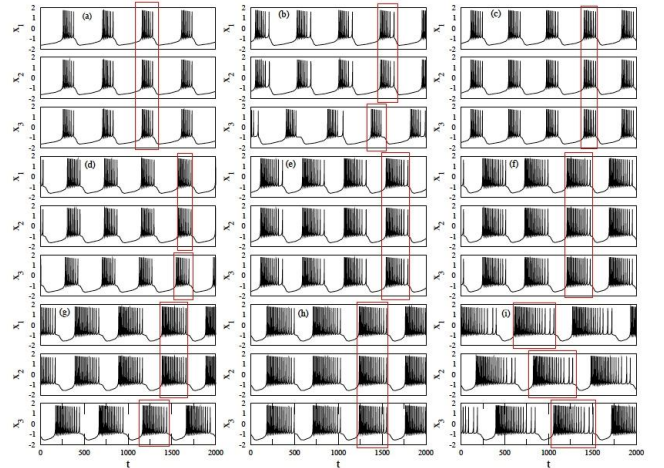


Figure 5: Changing of the burst synchrony cluster states with input for three Hindmarsh-Rose neurons governed by the system (3) and (4) with $n = 3$. The input current I has been increased from (a)-(i).

The input current has been increased from (a) to (i). The burst activity pattern from each cell is shown with the voltage variables x_1 , x_2 and x_3 . It is clear that the burst synchrony cluster changes as the input current is changed. The boxes enclose the bursts that are synchro-

nized. In panel (a) the bursts from the cell are synchronized for $I = 1.8$ while the bursts arrange into a 2-1 cluster for $I = 1.9$ shown in panel (b); in panel (i) we observe the bursts get desynchronized for $I = 3.2$ and evolve as rotating waves. One interesting feature is that the spike number in the bursts increases with input I .

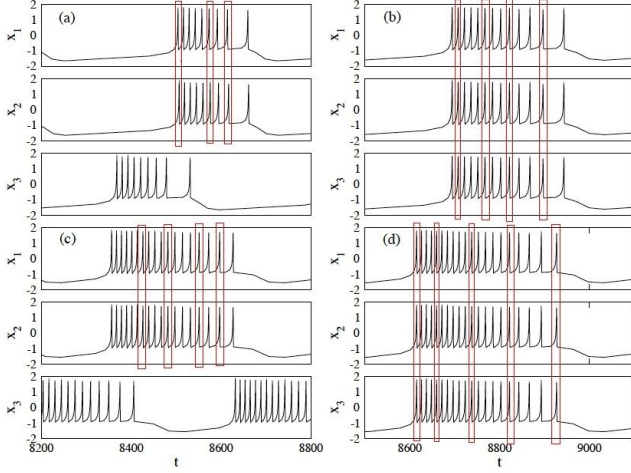


Figure 6: Spike synchrony properties in burst synchrony clusters of the three-coupled Hindmarsh-Rose system (3) and (4) with $n = 3$ with different input current I : (a) $I = 1.9$, (b) $I = 2.5$, (c) $I = 3.0$, (d) $I = 3.1$. The small boxes enclose spikes from synchronized bursts to signify spike synchrony patterns. Note in (a) the spikes are not exactly synchronized as in the other cases illustrated in (b), (c), and (d). Panels, (a) and (c), show 2-1 burst synchrony cluster while full burst synchrony pattern can be seen in (b) and (d).

3.2 Within-Burst Spike Synchrony

One interesting features of the spontaneous burst synchrony clusters is that the spikes within the synchronized bursts are not necessarily inphase. Fig. 6 shows the spike synchrony patterns for four different input parameter sets for three-Hindmarsh-Rose burster system. The system and details are as in Fig. 5. All the realizations have same initial conditions: $(0.1, 0, 0)$, $(0.15, 0, 0)$ and $(0.2, 0, 0)$. The system is subjected to different input currents from (a) to (d). In panel (a) the cells fire bursts and arrange in a 2-1 burst synchrony cluster. But a rather careful observation shows that the spikes are not synchronized (see the boxes). The other panels show burst synchrony clusters with fully synchronized spikes.

4 LYAPUNOV STABILITY OF THE CLUSTER STATES

4.1 Variational Equations of The Coupled Bursting System

In order to obtain the Lyapunov exponent for burst synchrony cluster we need derive a variational system about the cluster pair for a three-Hindmarsh-Rose burster system governed by (3) and (4) with $n = 3$. We denote three cells by indices '1', '2' and '3', and their dynamic variables are denoted with corresponding subscripts. We perturb the synchronized cell pair to derivethe variational equation of the clustered state that will be used to obtain the Lyapunov exponents to infer their stability status. To

begin with let us consider the case of 2-1 cluster state where the cells 1 and 2 fire inphase synchronous bursts while the bursts from the third cell are asynchronous to others. Suppose the perturbations are:

$$\xi_{12} = x_2 - x_1,$$

$$\eta_{12} = y_2 - y_1,$$

$$\zeta_{12} = z_2 - z_1. \quad (5)$$

As a result of this transformation we should end up with a nine-dimensional system of which six dimensions describe the dynamics of the cell 1 and cell 3 while the perturbation makes it way to the system with 3 dimensions involving ξ_{12} , η_{12} and ζ_{12} . Using the transformation (5):

$$\begin{aligned} \dot{\xi}_{12} &= \dot{x}_2 - \dot{x}_1 \\ &= \eta_{12} - a\xi_{12}(3x_1^2 + 3x_1\xi_{12} + \xi_{12}^2) + b\xi_{12}(2x_1 + \xi_{12}) - \zeta_{12} \\ &\quad + \kappa_1(-2\xi_{12} + \xi_{13} - \xi_{12} - \xi_{13}) \\ &\quad + \kappa_2(\xi_{12}^2 + (\xi_{13} - \xi_{12})^2 - \xi_{12}^2 - \xi_{13}^2) \\ &\quad + \kappa_3(-\xi_{12}^3 + (\xi_{13} - \xi_{12})^3 - \xi_{12}^3 - \xi_{13}^3) \\ &= \eta_{12} - a\xi_{12}(3x_1^2 + 3x_1\xi_{12} + \xi_{12}^2) + b\xi_{12}(2x_1 + \xi_{12}) - \zeta_{12} \\ &\quad - 3\kappa_1\xi_{12} - \kappa_2(2\xi_{13} - \xi_{12})\xi_{12} - \kappa_3(2\xi_{12}^3 + \xi_{13}^3 - (\xi_{13} - \xi_{12})^3) \end{aligned} \quad (6)$$

Here, $\xi_{13} = x_3 - x_1$ and κ_p , with $p = 1, 2, 3$, are the coupling coefficients. Now retaining only the linear terms, we obtain

$$\begin{aligned} \dot{\xi}_{12} &= \eta_{12} - 3a\xi_{12}x_1^2 + 2b\xi_{12}x_1 \\ &\quad - 3\xi_{12}\kappa_1 - 2\kappa_2\xi_{13}\xi_{12} - 3\kappa_3\xi_{13}^2\xi_{12} \end{aligned} \quad (7)$$

Similarly,

$$\begin{aligned} \dot{\eta}_{12} &= \dot{y}_2 - \dot{y}_1 \\ &= -d(x_2^2 - x_1^2) - (y_2 - y_1) \\ &= -d\xi_{12}(2x_1 + \xi_{12}) - \eta_{12}. \end{aligned} \quad (8)$$

Linearizing (8) about η_{12} we obtain

$$\dot{\eta}_{12} = -2d\xi_{12}x_1 - \eta_{12} \quad (9)$$

The variation between z_1 and z_2 follows as a linear form as

$$\dot{\zeta}_{12} = r(s\xi_{12} - \zeta_{12}) \quad (10)$$

Finally, the nine-dimensional system of equations with variational calculation for a 2-1 cluster system is as following:

$$\begin{aligned}
\dot{x}_1 &= y_1 - ax_1^3 + bx_1^2 - z_1 + I + K_1 \\
\dot{y}_2 &= c - dx_1^2 - y_1 \\
\dot{z}_1 &= r(s(x_1 - x_0) - z_1) \\
\dot{\xi}_{12} &= \eta_{12} - 3a\xi_{12}x_1^2 + 2b\xi_{12}x_1 \\
&\quad - 3\xi_{12}\kappa_1 - 2\kappa_2\xi_{13}\xi_{12} - 3\kappa_3\xi_{13}^2\xi_{12} \\
\dot{\eta}_{12} &= -2d\xi_{12}x_1 - \eta_{12} \\
\dot{\zeta}_{12} &= r(s\xi_{12} - \zeta_{12}) \\
\dot{x}_3 &= y_3 - ax_3^3 + bx_3^2 - z_3 + I + K_3 \\
\dot{y}_3 &= c - dx_3^2 - y_3 \\
\dot{z}_3 &= r(s(x_3 - x_0) - z_3).
\end{aligned} \tag{11}$$

Here K_1 and K_3 are the coupling terms in the first and third cell given as

$$K_1 = \sum_{p=1}^3 \kappa_p (\xi_{12}^p + \xi_{13}^p + \eta_{12}^p + \eta_{13}^p + \zeta_{12}^p + \zeta_{13}^p) \tag{12}$$

And

$$K_3 = \sum_{p=1}^3 \kappa_p (\xi_{31}^p + \xi_{32}^p + \eta_{31}^p + \eta_{32}^p + \zeta_{31}^p + \zeta_{32}^p) \tag{13}$$

Here, $\xi_{32} = x_2 - x_3$, $\eta_{32} = y_2 - y_3$ and $\zeta_{32} = z_2 - z_3$. The variational system (11) with (12) and (13) can be used for calculating Lyapunov exponent for the 2-1 burst synchrony cluster state as observed. The following expression implies the logarithmic deviation of the trajectories with coordinates (x_1, y_1, z_1) and (x_2, y_2, z_2)

$$L_{12} = 0.5 \log(\varepsilon + (x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2) \tag{14}$$

or

$$L_{12} = 0.5 \log(\varepsilon + \xi_{12}^2 + \eta_{12}^2 + \zeta_{12}^2) \tag{15}$$

Here, ε is an arbitrary small number to prevent blow-out in the logarithmic scale. The Lyapunov exponent can be computed from the expression by linear fitting of the generating curve. The gradient of the regression line is the Lyapunov exponent. The negative value, obviously, implies compression along the Euclidean distance between the two coordinates and thus the stability of the solution for the coupled system on the synchronization manifolds. Similarly, for 1-2 burst synchrony cluster where the second and third cell fire inphase bursts, the logarithmic deviation can be written as

$$L_{23} = 0.5 \log(\varepsilon + (x_2 - x_3)^2 + (y_2 - y_3)^2 + (z_2 - z_3)^2) \tag{16}$$

Or

$$L_{23} = 0.5 \log(\varepsilon + \xi_{23}^2 + \eta_{23}^2 + \zeta_{23}^2) \tag{17}$$

We may likewise derive a variational system for fully synchronized bursters. We consider the following perturbation in addition to (5):

$$\begin{aligned}
\xi_{13} &= x_3 - x_1, \\
\eta_{13} &= y_3 - y_1, \\
\zeta_{13} &= z_3 - z_1.
\end{aligned} \tag{18}$$

This perturbation obviously will account for the stability of synchrony state between cell 1 and cell 3 as well. By following the above method and linearization we obtain the following variational system for full synchrony state as

$$\begin{aligned}
\dot{x}_1 &= y_1 - ax_1^3 + bx_1^2 - z_1 + I + K_1 \\
\dot{y}_1 &= c - dx_1^2 - y_1 \\
\dot{z}_1 &= r(s(x_1 - x_0) - z_1) \\
\dot{\xi}_{12} &= (2bx_1 - 3ax_1^2 - 3K_1)\xi_{12} + \eta_{12} - \zeta_{12} \\
\dot{\eta}_{12} &= -2dx_1\xi_{12} - \eta_{12} \\
\dot{\zeta}_{12} &= r(s(\xi_{12} - \zeta_{12})) \\
\dot{\xi}_{13} &= (2bx_1 - 3ax_1^2 - 3K_1)\xi_{13} + \eta_{13} - \zeta_{13} \\
\dot{\eta}_{13} &= -2dx_1\xi_{13} - \eta_{13} \\
\dot{\zeta}_{13} &= r(s\xi_{13} - \zeta_{13}).
\end{aligned} \tag{19}$$

Here, coupling term K_1 given as

$$K_1 = \sum_{p=1}^3 \kappa_p (\xi_{12}^p + \xi_{13}^p + \eta_{12}^p + \eta_{13}^p + \zeta_{12}^p + \zeta_{13}^p) \tag{20}$$

This variational system offers useful opportunities to analyze the dynamics of the coupled system in terms of stability, bifurcation and phase space. Although the above transformation does not reduce the dimension of the system, it does not increase it either. Furthermore, the phase space between ξ_{12} and ξ_{13} can shed light on the stability of fully synchrony solutions for the original system. Moreover, the Lyapunov exponent in this case may be determined from the following logarithmic deviation

$$\begin{aligned}
L_{012} &= 0.5 \log(\varepsilon + (x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2 \\
&\quad + (x_1 - x_3)^2 + (y_1 - y_3)^2 + (z_1 - z_3)^2)
\end{aligned} \tag{21}$$

Or

$$L_{012} = 0.5 \log(\varepsilon + \xi_{12}^2 + \eta_{12}^2 + \zeta_{12}^2 + \xi_{13}^2 + \eta_{13}^2 + \zeta_{13}^2) \tag{22}$$

Here, ε is an arbitrary constant to prevent logarithmic blowout. In this case also the Lyapunov exponent is the gradient of the regression line L_{012} against t .

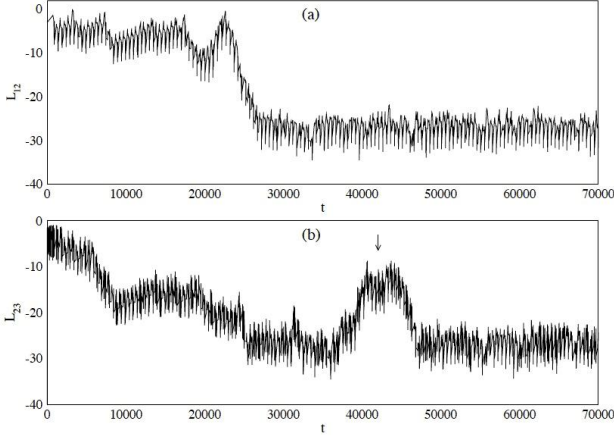


Figure 7: Stability of burst synchrony cluster states for three-coupled Hindmarsh-Rose burster system implied by the negative slope of the time series of L_{12} (14) and L_{23} (16): (a) 2-1 cluster and (b) 1-2 cluster.

4.2 Computation of Lyapunov Exponents for the Burst Cluster States

In this section we present a qualitative stability analysis of spontaneous burst synchrony cluster for three-Hindmarsh-Rose burster governed by (3) and (4) with $n = 3$ based on the method developed in the previous section. Fig. 7 demonstrates the time series of L_{12} and L_{23} . After an initial transient that may be very long, the final states are presumably chaotic. The negative slopes of L_{12} and L_{23} imply the 2-1 and 1-2 cluster states are stable. The initial conditions for (a) $(0.1, 0, 0), (0.15, 0, 0)$ and $(0.2, 0, 0)$; (b) $(-0.1, 0, 0), (0.15, 0, 0)$ and $(0.2, 0, 0)$. The parameters are as in Fig. 4. It is clear from the figure that both time series show negative slope for the corresponding logarithmic deviation, so the cluster states are stable.

One interesting feature can be observed in (b) that the transient state appears to be longer in the 1-2 burst cluster state. The system evolves through unstable burst synchrony states (shown with arrow) before the L_{23} starts to decrease implying negative slope and eventually stable 1-2 cluster occurs. Fig. 8 shows a couple of examples of computation of Lyapunov exponents for 2-1 and 1-2 burst synchrony cluster states using (22). The Lyapunov exponents are determined by computing the slope of the decreasing part of the time series (red boxes). The Lyapunov exponents are negative for both cases implying emergence of stable spontaneous burst clusters in each case. Hence, this method offers a basic means to determine the Lyapunov exponent of the synchronized state to understand the stability qualitatively.

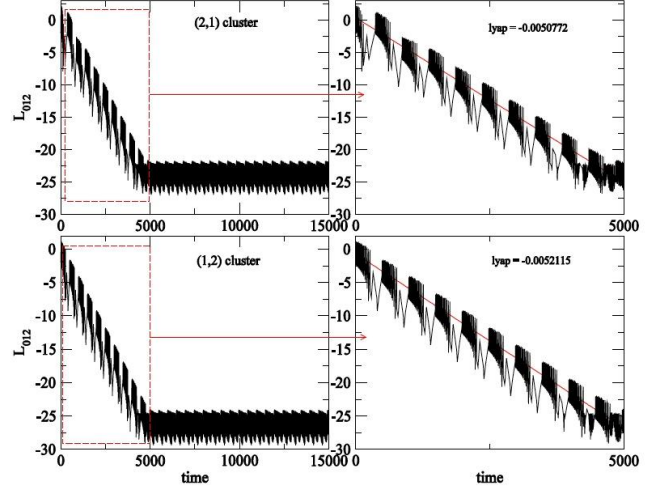


Figure 8: Computation of Lyapunov exponents for burst synchrony clusters: 2-1 cluster state (top) and 1-2 cluster state (bottom) using L_{012} (22).

5. BURST SYNCHRONY CLUSTER IN LARGER NETWORKS

In this section, we explore the burst synchrony cluster for larger system of coupled Hindmarsh-Rose burster. We consider mutually inhibitory coupled eight-Hindmarsh-Rose neurons governed by the system (3) and (4) with $n = 8$. Fig. 9 shows the result of the simulation in array diagram. The red part of the spectrum implies the higher values of action potential or voltage variables, so the red strips represent the burst active phase while the yellow strips represent the quiescent phase. The horizontal axis of the array diagram represents time that increases downwards and the vertical axis is segmented in eight parts each representing a cell. The parameters of the simulation are $a = 1, b = 3, c = 1, d = 5, I = 3, x_0 = -1.6, r = 0.001$ and $s = 4$; the coupling coefficient $\kappa_p = \kappa = -0.001$ where $p = 1, \dots, 8$. In this case all transients have been removed by running the system for a long time. It is clear from the diagram that the system yields burst synchrony clusters similar to smaller system demonstrated in Fig. 4. It is obvious that starting from left the first, fifth and seventh cells form one burst synchrony cluster, second, sixth and eighth cells form another burst synchrony cluster, while third and fourth cell form the third burst synchrony cluster.

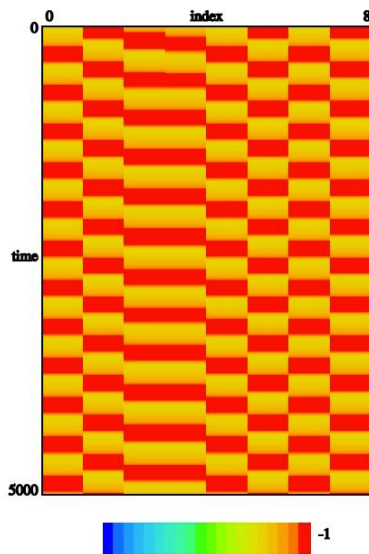


Figure 9: The array diagram showing spontaneous burst synchrony cluster in eight-Hindmarsh-Rose burster system.

6. CONCLUSION

The study confirms the burst synchrony cluster behaviour in the coupled Hindmarsh-Rose bursting neurons. The investigation was carried out over a small number of parameter values, and we expect to see wide variety of other typical behaviour [28]. Note the reported burst synchrony cluster emerges in the system with mutually inhibitory coupling; excitatory coupling results in inphase burst synchrony behaviour. Additionally, it is relatively easy to find burst synchrony clustering for the chosen nonlinear coupling scheme, whereas burst synchrony clusters are harder to achieve in systems with linear coupling. The observed spontaneous burst synchrony clustering in the network of Hindmarsh-Rose bursters suggests further investigations in the area of pattern generation in the biological systems will be of interest such as leech heart interneurons [26], [27]. Future investigation involves further analytical and numerical analyses of the larger network system to explore the dynamical origin of the cluster synchrony pattern and its biological significance.

ACKNOWLEDGMENT

The author wishes to thank Peter Ashwin, Alastair Ruckledge and Gabor Orotz for offering valuable comments and suggestions at different stage of conceptualization and execution of the work. The author also acknowledges Exeter Research Scholarships for supporting the work.

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Intelligent Vehicle System with a Wireless PC Interfacing

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Abstract—In this work an intelligent vehicle system has been designed using a microcontroller AT89C4051. The designed vehicle moves in a predetermined path and work automatically. The microcontroller performs the functions of self-controller of the vehicle. The microcontroller has been programmed in Machine Level Language to meet our criteria. Also a personal computer (PC) has been used to control the vehicle by RF link. Parallel printer ports of the PC has been used as data communication port to interface the remote vehicle. A suitable software program has been developed using C Language for the system controller to send commands to the vehicle.

Keywords—Microcontroller, PC Interfacing, Intelligent, Radio link, Data Communication and IR detector.

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Manuscript received on 31 July 2013 and accepted for publication on 8 September 2013

1 INTRODUCTION

NECESSITIES are the mother of inventions. Whenever human being finds the need of something it's led to a wonderful invention. As I all know that today is the era of revolution in electronics science and also in engineering is one of the roots of the science. Development in the field of electronic is the reaching far ahead whether it is an embedded system designing or CMOS technology. The aim of our design is such type of vehicle that can perform wide variety of difficult tasks in space research, domestic, scientific and industrial fields. With the advancement of software field every all devices are being automated and controlled by microcontroller through software application. On continuations with the growing advancement it is proposed to design a control system (robot i.e. car) which is based on combined applications of software as well as hardware.

For data communication between the control unit and the remote vehicle unit, two modes of data transfer: parallel and serial can be used. We have seen that in serial communication system a series of pulses are transmitted on a single wire. Hence for long distance data communication, the serial data transfer is preferred, as it is simple to control and also cost-effective.

Asynchronous communication is the prevailing standard in the personal computer industry, both because it is easier to implement and it has the unique advantage that bytes can be sent whenever they are ready. There need be no timing relationship between successive characters (or bytes of data). Individual characters may be separated by any arbitrary idle period. So we have employed asynchronous serial transmission format in the present work.

Simple, locally available and low cost components have been used in the present work to develop the motor driving circuit of the vehicle. Simple motor driving circuits have been used in the vehicle to move it in the desired direction noiselessly and efficiently by using a unipolar power supply.

2 MOTIVATION AND OUR APPROACH

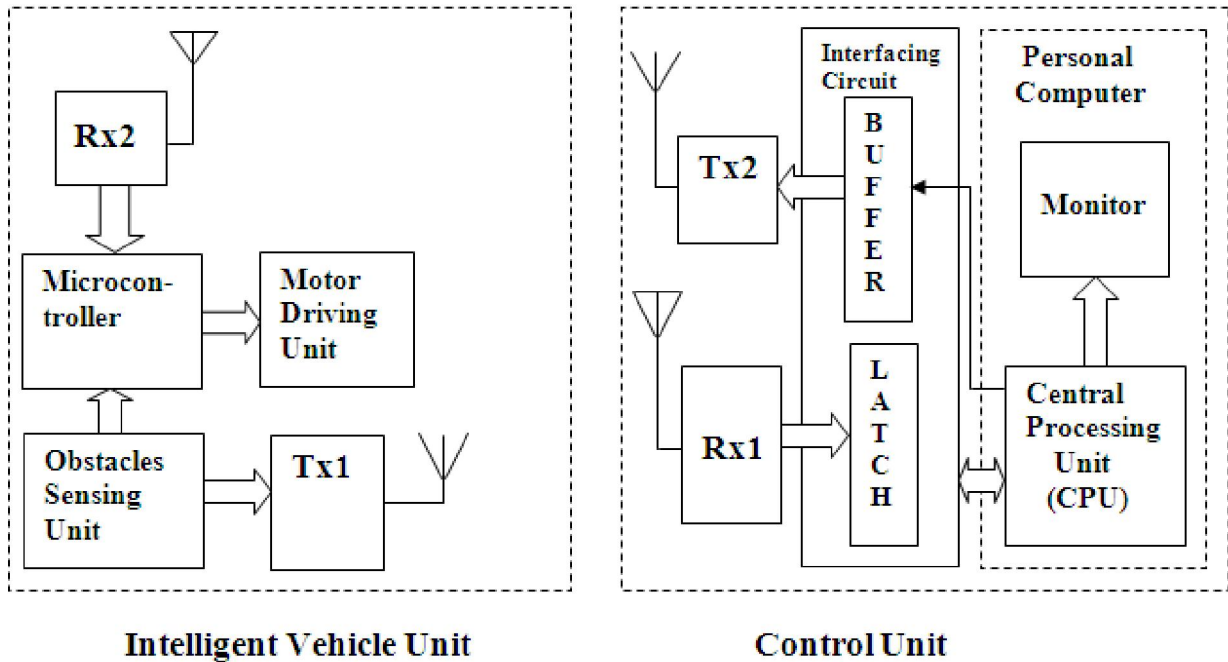
The main motivation for this work is twofold. First, in most of the reviewed references the authors primarily aim to achieve a high level of accuracy of their robotic vehicle design method. Our first goal was, therefore, to develop a computationally efficient and, more importantly, a robotic vehicle system that can move automatically. Second, to objectively quantify the performance of robotic vehicle, with special avoidance of obstacles neighboring it's. Our second goal was thus to acquire a large enough for space research or domestic uses. In this work we have design our system in such a way that the vehicle has self decision making ability and self motivated according to the designed program. Also this vehicle can communicate with the control unit (PC) via radio link or wireless communication. Share the obstacle position on it's path and take decision from the control unit.

3 SYSTEM DESIGN

The system is mainly divided into two units: intelligent vehicle unit and control unit. The intelligent vehicle unit

consists of obstacle sensing unit, microcontroller unit, motor driving unit and transceiver unit. The personal

simplified block diagram of the complete system is depicted in Figure 1.



computer with interfacing circuit works as control unit. A

Figure 1: A simplified block diagram of the complete system

3.1 Obstacle Sensing Unit

The function of this unit is to detect the presence of environmental obstacles (at any side of the vehicle) neighboring it's at a limited distance. The block diagram of the obstacle-sensing unit is shown in Figure 2.

If any obstacles presents in it's way, the sensors output goes high. The amplifier unit amplifies the output signals of the sensor unit that are appropriate for the microcontroller input and also for the RF- transmitter.

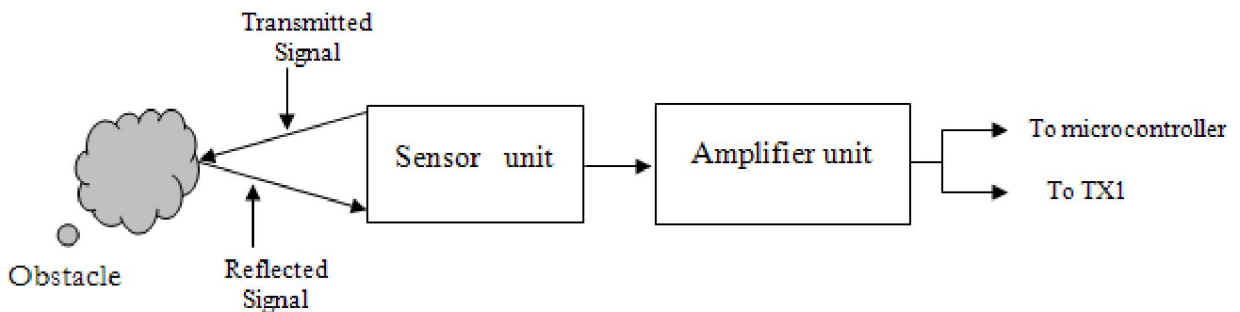


Figure 2: Block diagram of the obstacle-sensing unit

In this work for sensing obstacles on the way of the vehicle's destination near-Infrared Proximity Detectors have been used at various locations of the vehicle to detect obstacles from a limited distance and take necessary actions to overcome them.

3.2 The Microcontroller (AT89C4051) Unit

The AT89C4051 is a low-voltage, high-performance CMOS 8-bit microcomputer with 2K bytes of Flash programmable and erasable read-only memory (PEROM) [1]. The device is manufactured using Atmel's high-density

nonvolatile memory technology and is compatible with the industry-standard MCS-51 instruction set. By combining a versatile 8-bit CPU with Flash on a monolithic chip, the Atmel AT89C4051 is a power-full microcomputer which provides a highly-flexible and cost-effective. AT89C4051 provides the standard features [2]: Compatible with MCS®-51Products, 2K Bytes of Reprogrammable Flash Memory Endurance: 1,000 Write/Erase Cycles, 2.7V to 6V Operating Range , Fully Static Operation: 0 Hz to 24 MHz , Two-level Program Memory Lock, 128 x 8-bit Internal RAM , 15 Programmable I/O Lines , Two 16-bit Timer/Counters, Six Interrupt Sources, Programmable Serial UART Channel, Direct LED Drive Outputs , On-chip Analog Comparator, Low-power Idle and Power-down Modes, Green (Pb/Halide-free) Packaging Option.

In addition, the AT89C4051 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port and interrupt system to continue functioning.

The power-down mode saves the RAM contents but freezes the oscillator disabling all other chip functions until the next hardware reset.

3.3 Motor Driving Unit

The DC motor driving circuit is shown Figure 3. It consists of T1-T4, D1-D6, R1-R6 and dc motor [3]. When input is at logic '0' at both ends, transistors T1 and T2 are ON due to the current flow through resistors R1 and R2. As a result, voltage at both ends of the motor is the same and the net potential difference across the motor is zero and so the motor remains OFF. When the signal at transistor T3 is high (logic '1') and T4 is low that for the combination of D0=1 and D1=0 of the data, transistor T3 comes into saturation, grounding the base of T1 which is then driven into cutoff but T2 is ON. So current flows through the motor from T2 to D1 (diode) and then through T3 to ground the DC motor starts to rotate in one direction.

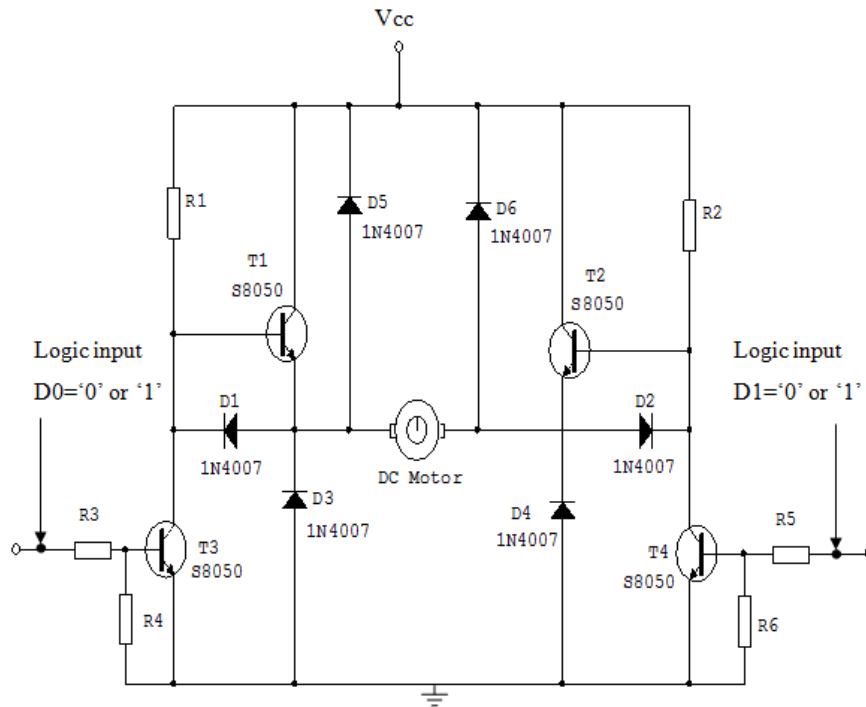


Figure 3: Motor driving circuits of the designed system

3.4 Interfacing Circuit

The PC interfacing circuit consists of two ICs [4]. They are

octal latch 74LS373 and octal buffer 74LS244. The simple interfacing circuit is depicted in Figure 4.

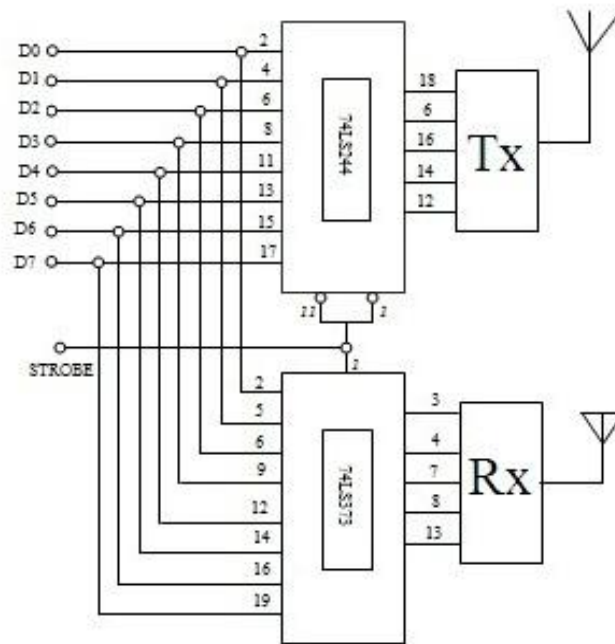


Figure 4: PC interfacing circuit

3.5 RF-Transceiver Unit

The RF Transceivers (Tx/Rx) provided the function of transmitting and receiving RF signals between the PC and the Intelligent Vehicle unit [5]. The 'Tx' radiates the electromagnetic wave to the air; on the other hand 'Rx' receives the electromagnetic wave and converts it to the electrical signal. The 49MHZ RF transceiver has been used to transmit signals from control unit and receives the same signals to the Intelligent Vehicle unit. The 27MHZ transceiver has been used to transmit signal from Intelligent Vehicle unit and receives the same signals to the control unit. The band-gap of these two transceivers is 22MHZ has been used to overcome the frequency interference. The used transceivers can transmit and receive four bit data.

4 SYSTEM PROGRAM

The system program and flow chart is depicted in Figure 5 that represents the control system of the intelligent vehicle. When the system is activated, it will invoke the microcontroller to reset all hardware devices in a normal and controlled mode. The robotic vehicle starts to move in forward direction and the obstacle sensing unit starts to detect the obstacle in it's path. If no obstacles finds the vehicle reach it's destination. If any obstacles are detecting in it's path the vehicle make decision according to the obstacles position and also move in desired path avoiding obstacles as shown in flow chart in Figure 5.

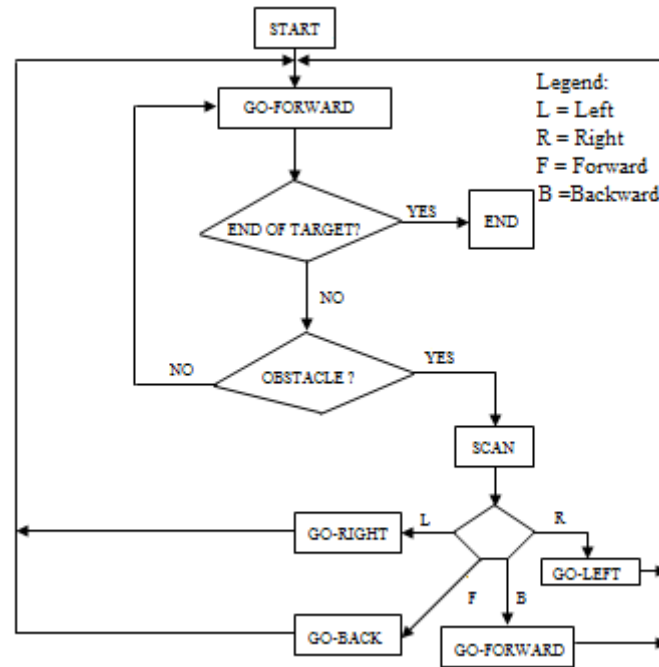


Figure 5: Flowchart for the developed system program

5 OBSTACLE AVOIDANCE ALGORITHM

Step-1: Move the vehicle in forward direction.

Step-2: No scan obstacle.

Go to Step-1.

Step-3: Scan obstacle.

i. Obstacle in it's front side

The vehicle stops for a little time and search **A or B**

A. Right side

No obstacle. Go to Step-1.

If obstacle. Go to Step-3.i.B

B. Left side

No obstacle. Go to Step-1.

If obstacle. Go to Step-3.ii.

ii. Scan backside.

a. No obstacle.

Go backward and then go to Step-1.

b. If obstacle. Go to Step-4.

Step-4: Stop and search for Step-1.

6 RESULTS AND DISCUSSION

The system was successfully developed and its performance was strong. It can move in a pre-determined path without any intervention from a human operator by sensing environment obstacles neighboring it's. Also it can control by a computer system. Here the computer (PC) works as the controller of the remote Intelligent Vehicle, which is interfaced with it through Radio link via parallel printer port.

The parallel printer port was used as a bi-directional data

communication port in SPP mode. Communication between the control unit (PC) and remote vehicle unit was done in serial form, since, for long distance communication this format is efficient and cost-effective than parallel. For data transmission asynchronous serial format was used in full-duplex mode. The computer commands are transmitted in serial binary data form to the remote Intelligent Vehicle, which are converted into parallel form using a serial to parallel converter. It is then used to activate the motor driving circuits according to the requirement.

For the system, the hardware portion was first designed and implemented and then software was developed to control the whole system. The software assists the computer (PC) to transmit the commands to the remote Intelligent Vehicle in serial binary form through the parallel printer port and also to receive data from the remote Intelligent Vehicle unit in the same form. Hence, this reduces the hardware portion for converting serial data into parallel form for transmission and vice-versa for reception. This modification increases the flexibility and reliability of the system.

When the RF-transmitter of the vehicle unit sends data to the computer, each bit position is specified for particular sensor reading. Five sensors are attached to the vehicle at different sides of it. The specific data bits used for signaling the sensor reading are given in the following Table 1. The Data bit combinations of different commands for controlling Intelligent Vehicle movements are shown in Table 2.

TABLE 1

DATA BITS SPECIFICATION FOR DIFFERENT SENSORS AT VARIOUS SIDES OF THE VEHICLE.

Location of Sensors	Data Bit used for Signaling
Front Down side of the vehicle	D0
Front side of the vehicle	D1
Back side of the vehicle	D2
Right side of the vehicle	D3
Left side of the vehicle	D4

TABLE 2

DATA BIT COMBINATIONS OF DIFFERENT COMMANDS FOR CONTROLLING INTELLIGENT VEHICLE MOVEMENTS

Obstacles Position	Data Bit Combinations								Movement of the Intelligent Vehicle
	Information bits								
	D7	D6	D5	D4	D3	D2	D1	D0	
Left + Right + Back side	X	X	X	X	1	1	1	0	Forward
Left + Right + Front side.	X	X	X	X	1	1	0	1	Backward
Left side	X	X	X	X	1	0	1	0	Forward + Right
Right side	X	X	X	X	0	1	1	0	Forward + Left
Left + Front side	X	X	X	X	0	1	0	1	Backward+ Right
Front + Right side	X	X	X	X	1	0	0	1	Backward + Left
Front + Left + Right + Back side	X	X	X	X	1	1	1	1	Stop
Switch off	X	X	X	X	0	0	0	0	

If any environmental obstacles are present neighboring it's, the obstacle sensing unit of the vehicle can sense that obstacles and sends the corresponding signals to the microcontroller and to the PC. The software scans these signals or data and analyzes to gives the proper instruction of the vehicle for moving in desired direction.

In this work, hardware designs of the receiver and transmitter are simple, reliable, and are developed by using low cost readily available components. For sensing obstacles on the way of the vehicle's destination Near-Infrared

Proximity Detectors have been used at various locations of the vehicle to detect obstacles from a limited distance and take necessary actions to overcome them. These sensors offer significant advantages over mechanical switches in such areas as stability, repeatability and long life. The motor driving circuits in the present work reverse the motor direction noiselessly and efficiently with the use of a unipolar power supply. The general specifications of the designed system are depicted in Table 3.

TABLE 3
GENERAL SPECIFICATIONS OF THE DESIGNED SYSTEM

Average velocity	14 cm / sec
Maximum distance of detecting any obstacles	30.5 cm
Rotational angle	90°
Transceivers radio frequency	49 MHZ / 27 MHZ
Types of sensors	IR detector
Maximum radio link distance	41.34 m
Length	35.5 cm
Width	14.1 cm
Weight	1.00 K.g

ences.

7 CONCLUSIONS

The designed system is fully software controlled. The use of single-chip microcontroller makes drastic reduction in size and cost of integrated circuits for constructing intelligent systems. PC offers a simple, flexible and reliable solution of the system. The most significant aspect of the software-controlled system is that it provides a well-structured control organization.

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Global Contrast Enhancement for Effective Medical Image Segmentation

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Abstract—Segmentation is a preliminary step to analyze medical images for computer-aided diagnosis and therapy. In this work a Global Contrast Enhancement (GCE) based technique is proposed to improve medical image segmentation for identifying tumors. At first medical image is pre-processed to reduce noise then multi-level histogram is generated and modified using GCE. Next, segmentation process is carried out for MRI and CT scan images. Segmentation results obtained by normal histogram, equalized histogram and GCE histogram are compared.

Keywords— Histogram Equalization and Modification, Global Contrast Enhancement, Medical Image Segmentation

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Manuscript received on 15 August 2013 and accepted for publication on 29 October 2013.

1 INTRODUCTION

IMAGE segmentation is increasingly used in analyzing medical imaging data sets. In modern medical science, segmentation accuracy is very important for computer-aided diagnosis and therapy. It is a difficult as well as challenging task due to the complex nature of medical images. There exist various methodologies for medical image segmentation but due to missing features and accuracy of the results are not up to the mark [1], [2], [3], [4]. In this paper a GCE-Based segmentation technique is proposed to improve the accuracy level of medical image segmentation. In addition to identify tumor area from MRI and CT scan segmented images, the proposed technique is smart enough in extracting other features and edges from the segmented medical images as well.

Previously, Tarik Arici [9] proposed a Global Contrast Enhancement Technique of histogram modification. However, it has not been applied widely due to accuracy.

With a view to improve the present segmentation methodology of MRI and CT scan images [8] we have successfully applied the GCE-Based technique and achieved better segmentation accuracy. Our aim is to achieve more accurate segmented result which is the key point for overall diagnosis. To confirm the effectiveness of the proposed method, an experiment is performed using 50 real MRI images and 50 real CT scan images with and without tumors. Images are collected from medical image database of internet.

The rest of the paper is organized as follows. Section 2 provides a description of the proposed technique. Evaluation process and concerns are presented in Section 3. Section 4 discusses the experimental results and analyzes the performance. Finally, conclusions are drawn in section 5.

2 METHODOLOGY

Image segmentation is the process of dividing an image into regions or objects. It is a basic step in image analysis. Segmentation accuracy determines the eventual success or failure of computerized analysis procedure [6], [11]. Magnetic Resonance Imaging (MRI) is an important diagnostic imaging technique utilized for early detection of abnormal changes in tissues and organs [9]. It possesses good contrast resolution for different tissues and is, thus, preferred over Computerized Tomography (CT) for brain study [6]. Therefore, the majority of research in medical image segmentation concerns MR images [6], [8], [10]. Since MR images are gray level image; the segmentation technique proposed in this paper is for gray-level images.

2.1 Histogram Equalization

Histogram equalization (HE) is an effective technique for contrast enhancement. However, HE without any modification usually results in excessive contrast enhancement, which in turn gives the processed image an unnatural look and creates visual artifacts [9]. As a result all details of the captured image are not revealed. HE enhances the contrast of images by transforming the values in an intensity image [5]. Mathematical expression for HE is given in equation (1).

$$x' = T(x) = \sum_{i=0}^x n_i \cdot \frac{\text{max. intensity}}{N} \quad (1)$$

where n_i is the number of pixels at intensity i ; N is the total number of pixels in the image. According to equation (1), the input pixel intensity, x is transformed to new intensity value, x' . The transform function, $T(x)$ is the product of a cumulative histogram and a scale factor. The scale factor is needed to fit the new intensity value within the range of the intensity values, for example, $0 \sim 255$.

2.2 Global Contrast Enhancement Based Histogram Modification

The level of contrast enhancement can be adjusted by introducing specifically designed penalty terms [9]; for obtaining more visually pleasing and informative image. In GCE-Based histogram modification technique minimum intensity of the image is the gray-level range for black stretching b and maximum intensity value is the gray-level range for white stretching w [9]. For each bin n of the input image histogram, the modified histogram is represented by equation (2).

$$\tilde{h} = \frac{h_i + \lambda u}{1 + \lambda} = \left(\frac{1}{1 + \lambda} \right) h_i + \left(\frac{\lambda}{1 + \lambda} \right) u, \quad b < n < w \quad (2)$$

Where $\tilde{h}$ is the modified histogram, h_i is the input histogram, λ is for achieving various level of contrast enhancement. By changing λ , the level of enhancement can be adjusted, u is the minimum between average intensity frequency and the most frequently occurred intensity value in the histogram.

Otherwise, the histogram is modified using the following equation (3).

$$\tilde{h} = ((1 + \lambda)I + \alpha I^B)^{-1} (h_i + \lambda u) \quad (3)$$

Where I^B is a diagonal matrix. $I^B(i,i) = 1$ for $i \in \{[0,b] \cup [w,255]\}$, and the remaining diagonal elements are zero. α is for the more natural look of the black and white in the image, which varies for different kind of images.

2.3 Global Contrast Enhancement (GCE) Based Segmentation Technique

Block diagram of the GCE-Based image segmentation process is presented in Figure 1. At first the input image is converted to grayscale and then resized to (256×256) . The whole process is divided into five distinct steps:

- Pre-processing:** At the pre-processing step, the Median filter is used to remove noise from the input gray scale image [8]. The moving window for the median filter is (3×3) .
- Edge Detection:** Sobel edge detector is used. The output image of the edge detection process is used to increase the intensity values of the edge pixels in the original image [8], [7].
- Histogram Construction:** Histogram of the resultant image, from step b, is constructed using equation (1).
- GCE Based Histogram Modification:** The generated histogram is modified using the GCE-Based histogram modification technique [9].
- Segmentation:** Output results are generated by multi-level segmentation (Multimodal Gray Scale Image Histogram Thresholding) technique.

3 EVALUATION PROCESS AND CONCERNS

The proposed method is implemented and tested in MATLAB R2009a environment by using a computer of Pentium 4, 2.8 GHz with 1 GB RAM in Windows XP platform. The efficiency of the proposed method is evaluated by both visual and numerical inspection.

3.1 Visual inspection

For visual inspection all resultant segmented MRI and CT scan images are analyzed by expert (radiologist) to find the most accurate result. The resultant segmented images using normal histogram H_i , equalized H_E and GCE-Based modified histogram methods are evaluated using a scale of 1 to 10. Score 10 is given when the segmentation is perfect while the score 1 is given when the segmentation accuracy is unacceptable [10].

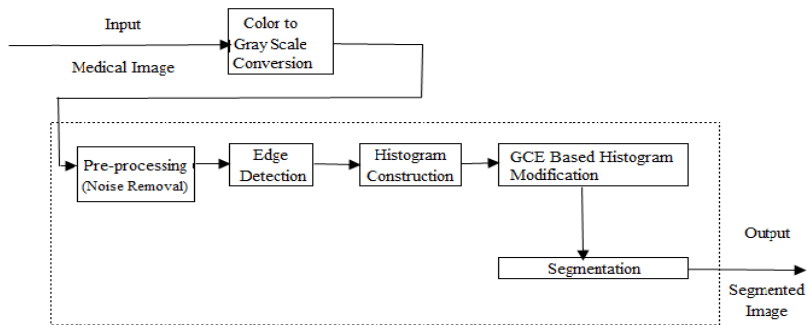


Figure 1: Block diagram of GCE-Based Segmentation Process

3.2 Numerical Inspection Using the Hausdorff Distance

In pattern recognition and computer vision field the central problem is determining the extent to which a shape resembles another shape [11]. For this work we have considered the Hausdorff distance in determining the extent to which a point of an 'image' resembles a point of a 'model' [11].

The Hausdorff distance

For a set $A = \{a1, \dots, ap\}$ and $B = \{b1, \dots, bp\}$ the Hausdorff distance between A and B is defined by equation (4) and equation (5).

$$H(A, B) = \max(h(A, B), h(B, A)) \quad (4)$$

With the directed Hausdorff distance defined as

$$\vec{h}(A, B) = \max_{a \in A} \min_{b \in B} \|a - b\| \quad (5)$$

Equation (4) is for scalar and equation (5) for vector representations.

4 EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 2 and Figure 3 show the comparative segmentation results. The former showing for MRI and the latter for CT scan images. Both Figure 2 and Figure 3 show that tumor area is detected in segmented MRI and CT scan medical images more clearly and correctly by using GCE-Based segmentation technique. In quantitative analysis the segmented images are compared using Hausdorff distance [12]. Ground truth images are prepared from original MRI and CT scan images by manual segmentation in the presence of a radiologist. After that Hausdorff Distance is calculated for the ground truth and segmented images [11]. The result analysis is concluded with the use of three types of histograms (Hi, HE and GCE). TABLE 1 and TABLE 2 summarize the average results of visual and numerical inspections.

Visual inspection results in TABLE 1 show that, the highest degree of accuracy of segmentation (for MRI 8.34 and for CT scan Image 8.18) is achieved by GCE-Based technique. Numerical Inspection results in TABLE 2 show that, by using GCE-Based segmentation technique, Hausdorff Distance is decreased by 8.68% for MRI and 7.14% for CT scan medical image. This means closely ground truth images are generated by GCE-Based method rather than the histogram equalization technique.

The proposed method can be applied not only for medical imaging, but can also be applied to any image processing problems in which segmentation is required. Here are some scopes or good challenges for future work. The proposed methodology can be further extended to adapt various filters at the last stage of the process after the segmentation. For X-ray and Ultrasound medical images the proposed method can be further evaluated. Rather than the use of sobel edge detector at the edge detection step [7], other edge detector operators like

Canny, Prewitt, Roberts, Laplacian etc. can be investigated.

At the pre-processing step, instead of median filter, other noise removing techniques can be adopted as well for specific type of noise (i.e. despeckle noise) in input images.

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TABLE 1
VISUAL INSPECTION RESULTS FOR MRI AND CT SCAN IMAGES

Image Histogram used in Medical Image Segmentation	Degree of Accuracy of the Segmentation (out of 10)	
	MRI Medical Image	CT Scan Medical Image
Normal Histogram (Hi)	5.5	3.96
Equalized Histogram (HE)	5.6	3.89
GCE-Based Modified Histogram	8.34	8.18

TABLE 2
NUMERICAL INSPECTION RESULTS USING HAUSDORFF DISTANCE FOR MRI AND CT SCAN IMAGES

Image Histogram used in Medical Image Segmentation	Hausdorff Distance Decreased By (%)	
	MRI Medical Image	CT Scan Medical Image
Equalized Histogram (HE)	0	0
GCE-Based Modified Histogram	8.68	7.14

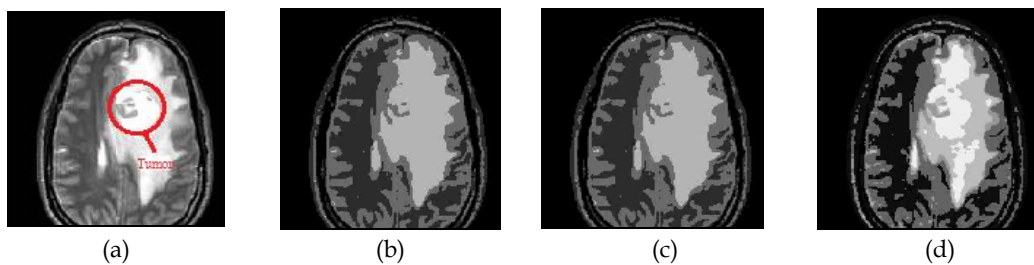


Figure 2: Comparison results of MRI medical image segmentation (a) tumor in original brain MRI; resultant segmented image using (b) normal histogram method (c) histogram equalization method and (d) GCE-Based histogram modification method

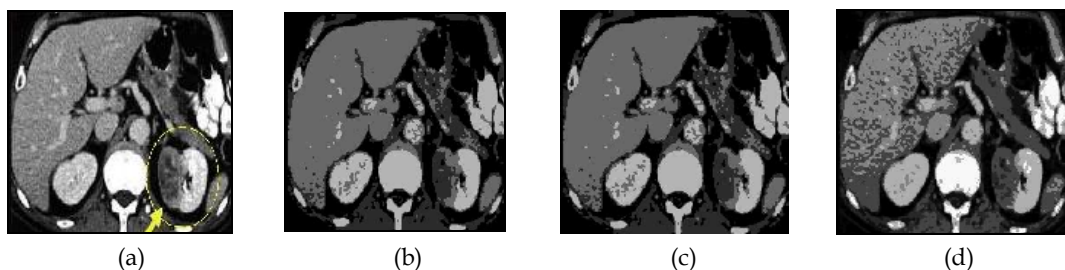


Figure 3: Comparison results of CT scan medical image segmentation (a) tumor in original kidney CT scan (Renal tumor); resultant segment image using (b) normal histogram method (c) histogram equalization method and (d) GCE-Based histogram modification method

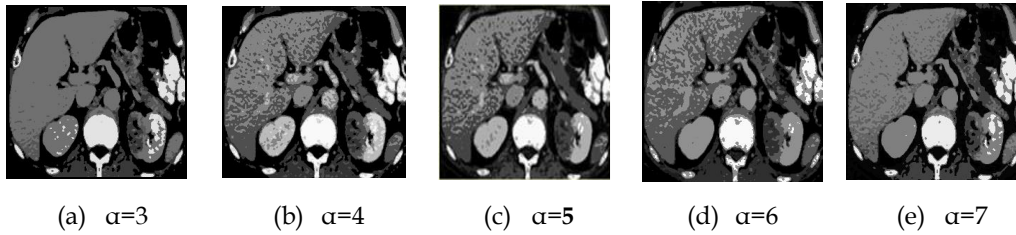


Figure 4 : Effects of different level of enhancement value α on segmentation results of Kidney Tumor CT scan image using GCE-Based Segmentation Method (a) $\alpha=3$ (b) $\alpha=4$ (c) $\alpha=5$ (d) $\alpha=6$ (e) $\alpha=7$

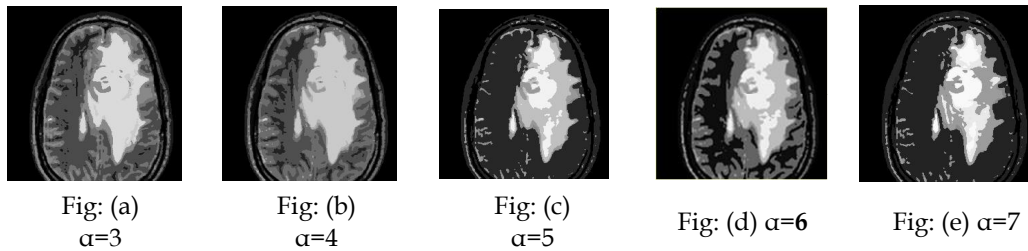


Figure 5: Effects of different level of enhancement value α on segmentation results of Brain Tumor MRI using GCE-Based Segmentation Method (a) $\alpha=3$ (b) $\alpha=4$ (c) $\alpha=5$ (d) $\alpha=6$ (e) $\alpha=7$

Figure 4 and Figure 5 show the performance under different values of α ($=3, 4, 5, 6, 7$) for MRI and CT scan images respectively. It is difficult to set the level of enhancement α automatically. In this paper we have taken the opinion of expert (radiologist) to set the value of α . According to expert's visual evaluation the value of α is set to 5 for MRI segmentation and for CT scan image segmentation its set to 6. Adaptive setting of α is very important which we will investigate in our next work. The system works for still images only, not able to segment real time images.

5. CONCLUSION

In this paper an effective GCE based segmentation method is proposed. The method generates segmented medical image based on GCE based histogram modification. Experimental results show that the method is quite successful in identifying tumors and other features from resultant segmented image. We Hope this technique will help in increasing the accuracy of computer guided surgery, therapy and other medical data set analysis as well. We have not tested our method for X-ray and ultrasound medical image. In the future, we would like to investigate on X-ray and ultrasound images.

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A Mathematical Model for Steady State Analysis of Commutatorless DC Shunt Motors

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Abstract – This paper presents steady state analysis of a line commutated inverter (LCI) fed synchronous motor (equivalent of commutatorless DC shunt motor) by using rotor position sensor technique. The firing pulses for thyristor of the inverter are generated in the proper sequence with the help of rotor position sensor of the synchronous machine. Performance characteristic of LCI fed synchronous motor in shunt mode is computed from the mathematical model. In this simulation experiment, the firing pulses for thyristor of the inverter are generated in proper sequence with the help of rotor position sensor of the synchronous machine. The steady state characteristics of the system are found similar to those of the conventional DC shunt motor.

Keywords – Mathematical Model, Rotor Position Sensor, LCI, FORTRAN Power Station, Model of Commutatorless DC Shunt Motor.

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Manuscript received on 7 March 2013 and accepted for publication on 22 May 2013.

1 INTRODUCTION

RECENTLY, variable speed drives have been widely used in modern industrial fields. From the outset, the conventional DC motor was used as variable speed drives in many industrial applications [1]. However for a reliable system operation, DC motor drives are not recommended in many cases. DC motor drives have several drawbacks, such as brush and commutator wear, which occurs as a result of friction and sparking; power loss, due to both brush contact points; mechanical commutator needs regular maintenance; the commutator construction increases the cost of the DC motor drive; and the mica insulation limits the voltage between commutator segments.

A DC motor can be considered as an AC synchronous machine in which the field is stationary and the armature with its multiphase AC winding is rotating. The armature receives AC power from a DC source through brushes and commutators. The brushes and the commutator constitute an inverter sensitive to the rotor position. Similarly, a synchronous motor may be operated as a DC motor. In a synchronous machine the field rotating, whereas the armature is stationary but it should be supplied by an inverter controlled by rotor position sensing signals [1]. The line commutated inverter with rotor position sensing controller is very well than the mechanical commutator. A line commutated inverter (LCI) fed synchronous motor can be used most economical, as variable speed drives substitute conventional DC motor drives for a wide range of speeds [2-4]. A synchronous motor supplied by a line commutated inverter acts as a commutatorless DC motor. The drives have several advantages. Like this, synchronous machines are rugged, reliable and trouble free. A large volume of research has been undertaken on the

series type commutatorless DC motors. From literature review [5-11], it is however; found that no steady state and transient analysis have been reported in the field of commutatorless DC shunt motor.

Hence, this paper presents the steady state performance equation of a commutatorless DC shunt motor from its mathematical model. The model is developed from the equivalent circuit of a commutatorless DC shunt motor.

2 SYSTEM DESCRIPTION

The block diagram of the commutatorless DC shunt motor is shown in Fig.1. It is comprised of an auto transformer, uncontrolled rectifier bridge, DC link smooth inductor, line commutated inverter and a three phase synchronous machine. The uncontrolled rectifier, together with the smoothing inductor, acts as a DC current source. Its output IDC is impressed at the DC input of the machine voltage commutated inverter.

The synchronous machine is interfaced with a DC power supply by a self control variable frequency static inverter, which switches the power to the appropriate stator winding of the synchronous machine. The excitation winding of the synchronous machine is connected to shunt with extra resistance (r_i) to the input of inverter.

For better understanding of the system operation, the major components are discussed briefly as follows:

(i) Uncontrolled diode bridge

The diode bridge's function is to rectify the fixed frequency AC supply to DC voltage (VD) and to supply the active power for the synchronous machine.

(ii) DC Link inductor

The variable voltage is applied to the DC link choke, which blocks the voltage ripple and smooths the DC link and suppress the harmonics contained in the output of the bridge rectifier. The DC link inductor acts as a current source.

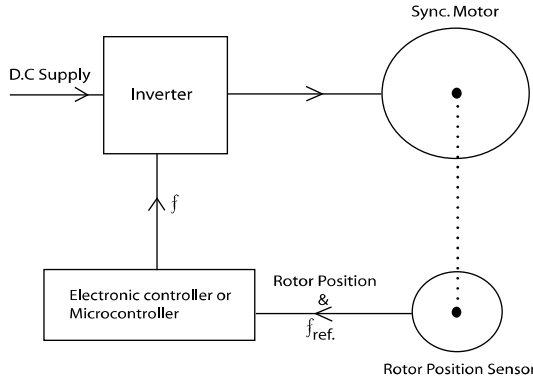


Figure 1: Block Diagram of Commutatorless D.C. Shunt Motor

(iii) Line commutated inverter (LCI)

This is a simple three-phase thyristor inverter bridge. The commutation of inverter thyristor is performed by the voltage induced in the stator winding of the synchronous machine, which is seen by the inverter as a three phase AC source of terminal voltage V_{SY} . The firing angle of the inverter is always greater than 90 degrees and it is measured from the instant of crossing point two phase voltages. It is a self-controlled inverter, which produces variable frequency in accordance to reference frequency (f_{ref}) of rotor position sensor.

(iv) Synchronous Machine

The synchronous machine is conventional and operated as a variable speed machine. The field winding of the machine is connected separately. The machine runs at a synchronous speed that corresponds with the rotor speed. Thus, the inverter frequency is a function of the machine speed. When a synchronous motor operates under steady-load conditions and an additional load is suddenly applied, the developed torque is less than that required by the load, so the motor begins to slow down. A gentle reduction in speed decreases the frequency of the induced e.m.f [3]. The firing control scheme generates the firing pulse for LCI at a new frequency.

(v) Rotor Position Sensor

Rotor position sensor measures the value of the displacement angle between stator pole axis and rotor pole axis of a synchronous machine. It produces an analog signal in respect to displacement angle, in between stator and rotor. The output signal is sent to the controller or microcontroller based firing circuit to produce inverter frequencies.

Brushless drives are basically synchronous motor drives in self-control mode. The armature supply frequency changes in proportion to rotor speed changes, so that the armature field always moves at the same speed as the

rotor. Self-control ensures that in all operating points, the armature and rotor fields move at exactly the same speed. This prevents the motor from pulling out of step, hunting oscillations, and the instability which results from a step change in torque or frequency. Accurately tracking speed is usually obtained using a rotor position sensor [1].

(vi) Electronic Control Circuit based or Microcontroller based firing circuit

The rotor position signal is fed to electronic control circuit or microcontroller for firing control of the inverter thyristor in proper sequence.

3 ANALYSIS

In this paper, the steady state performance equation of a commutatorless DC motor is developed. Simple effective equivalent circuits are presented for commutatorless DC shunt motor system during the conduction and commutation intervals. The performance equation of the commutatorless DC shunt motor was derived using the equivalent circuit Fig.2 and vector diagram Fig.3 [1]. The block diagram of the system shown in fig.1 consists of an auto-transformer, an uncontrolled bridge rectifier, a DC link inductor, a line commutated inverter, rotor position sensor and a conventional synchronous machine. The average DC output voltage of the rectifier is controlled by an auto transformer. The three phase uncontrolled bridge rectifier and DC link inductor act as a DC current source for the line commutated inverter. The equivalent circuit diagram of commutatorless shunt motor shown in Fig. 2 finds the inverter input voltage.

$$V_{DC} = V_D - I_{DC} r_d \quad (1)$$

We know, general equation of synchronous motor,

$$V_{SY} = E_{SY} + I_{SY} (R_{SY} + j X_S) \quad (2)$$

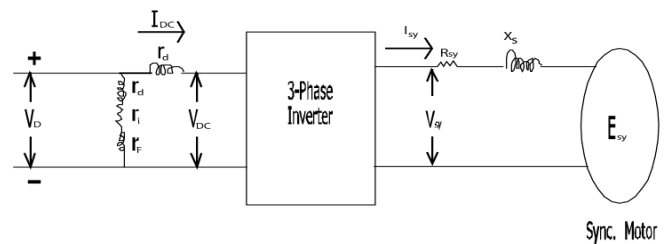


Figure 2: Equivalent Circuit Diagram of Commutatorless Motor

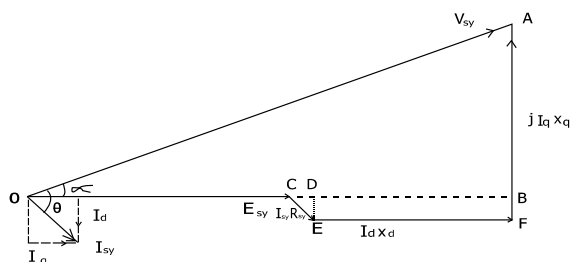


Figure 3: Vector Diagram of Commutatorless D.C Motor

From From vector diagram

$$(V_{SY})^2 = \{E_{SY} + I_{SY} R_{SY} \cos(\theta - \alpha) + I_d X_d\}^2 + \{I_q X_q \cos(\theta - \alpha) - I_{SY} R_{SY} \sin(\theta - \alpha)\}^2$$

$$(V_{SY})^2 = (E_{SY} + I_{SY} R_{SY} \cos \gamma + I_d X_d)^2 + (I_q X_q \cos \gamma - I_{SY} R_{SY} \sin \gamma)^2$$

Where, $\gamma = \theta - \alpha$, θ = p. f. angle, α = Load angle,

$$I_d = I_{SY} \sin \gamma, I_q = I_{SY} \cos \gamma$$

$$(V_{SY})^2 = (E_{SY} + I_{SY} R_{SY} \cos \gamma + I_{SY} X_d \sin \gamma)^2 + (I_{SY} X_q \cos \gamma - I_{SY} R_{SY} \sin \gamma)^2$$

$$E_{SY} = \sqrt{(V_{SY})^2 - (I_{SY} X_q \cos \gamma - I_{SY} R_{SY} \sin \gamma)^2} - (I_{SY} R_{SY} \cos \gamma + I_{SY} X_d \sin \gamma) \quad (3)$$

Inverter Relationship [12] & [13]:

$$V_{DC} = \frac{3\sqrt{6}}{\pi} V_{SY} \cos \beta \quad (4)$$

(Commutation reactance is neglected here)

$$\beta = 180 - \alpha' \quad \frac{\pi}{2} \leq \alpha' \leq \pi \text{ (for LCI)}$$

Where, V_{DC} = Inverter input voltage

β = Inverter lead angle in electrical degree.

α' = Inverter firing angle in electrical degree.

$$I_{SY} = \frac{\sqrt{6}}{\pi} I_{DC} \quad (5)$$

where,

No load current of motor, $I_{SY}=1.09$ A

No load inverter input current, $I_{DC}=1.40$ A (From equation 5)

And Full load current of motor $I_{SY}=10.8253$ A

Full Load inverter input current $I_{DC}=13.8840$ A (From equation 5)

Speed or frequency of commutatorless motor is dependent on rotor position angle. The maximum displacement of load angle is 20 degree (elect.) [14], [15].

The electronic controller circuit should have calibration of inverter frequency in according to load angle displacement, whose calibration shown in Table 1.

TABLE 1

VARIA TION OF INVERTER FREQUENCY WITH LOAD ANGLE DISPLACEMENT

Load Angle (α)	Inverter output frequency (f)
0 Degree	50 Hz
20 Degree	45 Hz

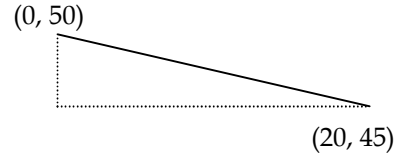


Figure 4: Relationship between load angle and inverter frequency

We have found that the relation between inverter input current in according to load angle displacement [14], [15], which's shown in Table 2.

TABLE 2

VARIA TION OF INVERTER INPUT CURRENT WITH LOAD ANGLE DISPLACEMENT

Load Angle (α)	Inverter input current (I_{DC})
0 Degree	1.40
20 Degree	13.95

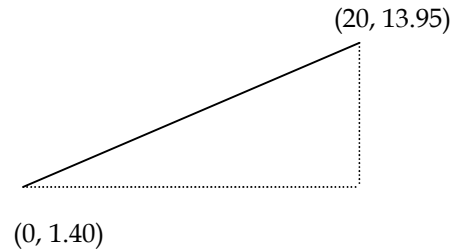


Figure 5: Relation between load angle and inverter input current

From Fig. 4, we have found that the relation between inverter frequency (f) and load angle (α) is:

$$f = 50 - 0.25 \alpha \quad (6)$$

$$X_q = 2\pi f L_q = 2\pi(50 - 0.25 \alpha) L_q \quad (7)$$

$$X_d = 2\pi f L_d = 2\pi(50 - 0.25 \alpha) L_d \quad (8)$$

where:

X_d = Direct axis reactance of synchronous machine.

X_q = Quadrature axis reactance of synchronous machine.

Fig.5 finds that the relationship between current (I_{DC}) and load angle (α) is:

$$I_{DC} = 1.40 + 0.6242 \alpha \quad (9)$$

From equations (1) and (4), we get the following quation,

$$V_{SY} = \frac{\pi(V_D - I_{DC} r_d)}{3\sqrt{6} \cos \beta} \quad (10)$$

From equation (3), (5) and (10) and we get the following quation,

$$E_{SY} = \sqrt{\left\{ \frac{\pi(V_D - I_{DC} r_d)}{3\sqrt{6}\cos\beta} \right\}^2 - 6\left(\frac{I_{DC}}{\pi}\right)^2 (X_q \cos\gamma - R_{SY} \sin\gamma)^2} - \sqrt{6\left(\frac{I_{DC}}{\pi}\right)(R_{SY} \cos\gamma + X_d \sin\gamma)} \quad (11)$$

It is found that the inverter frequency (equation 6) and the value of E_{SY} (equation 11) varies with the load angle from 0 to 20 degree (elect.) and the results are shown in results Table 3. Values of f (equation 6) and E_{SY} (equation 11) for different values of α .

TABLE 3

VARIATION OF INDUCED E.M.F OF SYNCHRONOUS MOTOR WITH INVERTER FREQUENCY

Load Angle in Degrees (α)	Inverter Output Frequency(Hz) (f)	E_{SY} (Volts)
0	50	215.0195
1	49.75	208.53
2	49.5	202.22
3	49.25	196.10
4	49	190.16
5	48.75	184.40
6	48.5	178.82
7	48.25	173.42
8	48	168.1835
9	47.75	163.1218
10	47.5	158.2250
11	47.25	153.49
12	47	148.9090
13	46.75	144.4802
14	46.5	140.1971
15	46.25	136.06
16	46	132.0434
17	45.75	128.16
18	45.5	124.40
19	45.25	120.7395
20	45	117.18

The relationship between the frequency value (f) and the value of induced e.m.f. (E_{SY}), with the help of Table-3 is as follows:

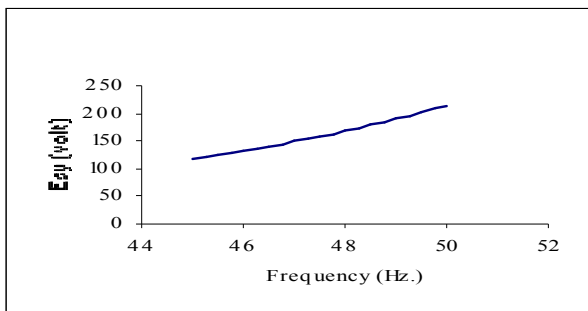


Figure 6: Relation between inverter frequency and induced e.m.f of synchronous motor.

From following of frequency (f) and induced e.m.f (E_{SY}), we get the Fig.6 which shows exact variation. It is observed that the variation is approximately straight line. If we assume variation of frequency and induced e.m.f as straight line, we can write equation,

$$f = 45 + \frac{5}{97.8395} (E_{SY} - 117.18) \quad (12)$$

We know that:

Motor speed, $N = 120 f / P$ [where, no. of pole=4]

Motor speed, $N = 120 f / P$

$N = 1350 + 1.53$

$$\left[\sqrt{\left\{ \frac{\pi(V_D - I_{DC} r_d)}{3\sqrt{6}\cos\beta} \right\}^2 - 6\left(\frac{I_{DC}}{\pi}\right)^2 (X_q \cos\gamma - R_{SY} \sin\gamma)^2} - \sqrt{6\left(\frac{I_{DC}}{\pi}\right)(R_{SY} \cos\gamma - X_d \sin\gamma)} - 117.18 \right] \quad (13)$$

Torque developed by the motor,

$$T_m = \frac{3E_{sy} I_{sy} \cos(\theta - \alpha)}{\omega}$$

$$T_m = \frac{3E_{sy} I_{sy} \cos(\theta - \alpha)}{2\pi N_{rps}} \quad \left[\text{where } N_{rps} = \frac{N}{60} \right]$$

$$T_m = \frac{3 \times 60 \times E_{sy} \sqrt{6} I_{DC} \cos(\theta - \alpha)}{2\pi N \pi}$$

$$T_m = \frac{22.34 E_{sy} (1.40 + 0.6242\alpha) \cos(\theta - \alpha)}{N}$$

[If, $K=22.34$]

$$T_m = \frac{K E_{sy} (1.40 + 0.6242\alpha) \cos(\theta - \alpha)}{N} \quad (14)$$

The speed equation (13) and torque equation (14) are the steady state equation of commutatorless DC shunt motor for 6 KW (3-phase, 4 poles) capacities. The load angle leads all the parameter of X_q (equation 7), X_d (equation 8) and I_{DC} (equation 9). Here the speed of commutatorless DC shunt motor is dependent on the value of load angle, D.C link voltage and firing angle of inverter. Thus the machine torque (equation 14) depends on load angle (α).

Development of Mathematical Model for all Capacities Motor:

To derive the general equation (i.e. speed, torque and power etc) of commutatorless DC shunt motor for all capacities.

From Fig.5 can be convert as

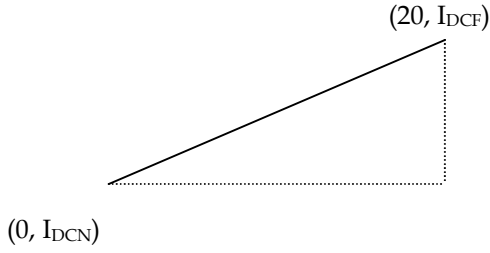


Figure 7: Relation between load angle and inverter input current for all capacities of commutatorless DC shunt motor

where,

I_{DCN} = No load inverter input current.

I_{DCF} = Full load inverter input current.

From Fig. 7, we find the relation between inverter input current (I_{DC}) and load angle (α) is:

$$I_{DC} = I_{DCN} + \frac{(I_{DCF} - I_{DCN})}{20} \alpha \quad (15)$$

From Fig. 6 can be convert as,



Figure 8: Relation between inverter frequency and induced e.m.f for all capacities of commutatorless DC shunt motor.

From Fig. 7, we find the relation between frequency (f) and induced (ESY) is:

$$\frac{f - 45}{45 - 50} = \frac{E_{SY} - E_{SYFL}}{E_{SYFL} - E_{SYNL}}$$

$$f = 45 + \frac{5}{E_{SYNL} - E_{SYFL}} (E_{SY} - E_{SYFL}) \quad (16)$$

We know that,

Speed of commutatorless D.C. shunt motor,

$$N = 120 f / P$$

(where, number of pole, $P=4$)

$$N = 1350 + \frac{150}{E_{SYNL} - E_{SYFL}} [E_{SY} - E_{SYFL}]$$

where,

$$E_{SYNL} = \sqrt{\left\{ \frac{\pi(V_D - I_{DCN}r_d)}{3\sqrt{6}\cos\beta} \right\}^2 - 6\left(\frac{I_{DCN}}{\pi}\right)^2 (X_q \cos\gamma - R_{SY} \sin\gamma)^2} - \sqrt{6} \left(\frac{I_{DCN}}{\pi}\right) (R_{SY} \cos\gamma + X_d \sin\gamma)$$

is induced e.m.f of synchronous motor at no load (I_{DC}) current

$$E_{SYFL} = \sqrt{\left\{ \frac{\pi(V_D - I_{DCF}r_d)}{3\sqrt{6}\cos\beta} \right\}^2 - 6\left(\frac{I_{DCF}}{\pi}\right)^2 (X_q \cos\gamma - R_{SY} \sin\gamma)^2} - \sqrt{6} \left(\frac{I_{DCF}}{\pi}\right) (R_{SY} \cos\gamma + X_d \sin\gamma)$$

is induced e.m.f of synchronous motor at full load (I_{DC}) current.

- (i) Speed of commutatorless motors for all capacities of motors:

$$N = 1350 + \frac{150}{E_{SYNL} - E_{SYFL}} [E_{SY} - E_{SYFL}]$$

$$N = 1350 + \frac{150}{E_{SYNL} - E_{SYFL}} \times$$

$$\left[\sqrt{\left\{ \frac{\pi(V_D - I_{DC}r_d)}{3\sqrt{6}\cos\beta} \right\}^2 - 6\left(\frac{I_{DC}}{\pi}\right)^2 (X_q \cos\gamma - R_{SY} \sin\gamma)^2} - \sqrt{6} \left(\frac{I_{DC}}{\pi}\right) (R_{SY} \cos\gamma + X_d \sin\gamma) - E_{SYFL} \right] \quad (17)$$

- (ii) Torque developed by the motors for all capacities of motors:

$$T_m = \frac{kE_{SY} \cos(\theta - \alpha)}{N} \left[I_{DCN} + \frac{(I_{DCF} - I_{DCN})}{20} \alpha \right] \quad (18)$$

- (iii) Input power of commutatorless motors for all capacities of motors:

Putting the value of I_{DC} from (15) into the fundamental equation $P_{DC} = V_D I_{DC}$,

$$P_{DC} = V_D I_{DCN} + V_D \frac{(I_{DCF} - I_{DCN})}{20} \alpha \quad (19)$$

Speed equation (17) torque equation (18) and motor input

power equation (19) are steady state general equation for all capacities of commutatorless DC shunt motor. Here, load angle leads all parameter of X_q (equation 7), X_d (equation 8) and I_{DC} (equation 15) as expected. The speed of commutatorless D.C. shunt motor is dependent on the value of load angle, D.C link voltage and firing angle of inverter. Similarly the motor torque (equation 18) and motor input power (equation 19) depend on load angle (α).

4 RESULTS AND DISCUSSION

The steady state performance of the commutatorless DC motor is computed using the mathematical equations (13) and (14). FORTRAN power station program has been used for the computation of the characteristics of the drive. The following steady-state characteristics of the drive are derived from the computed results:

- i) Speed Vs DC link current i.e. N / I_{DC} characteristic.
- ii) Torque Vs DC link current i.e. T_m / I_{DC} characteristic.
- iii) Speed Vs Torque i.e. N / T_m characteristic.

The analytical characteristics of the commutatorless DC motor are shown in Fig. 9 to Fig. 11. The following salient features on the performance of commutatorless DC motor may be observed from the computed results.

- i) The variation of speed with the DC inverter input current is shown in Fig. 9. It is observed from Figure 9 that the speed of synchronous machine slightly decreases with the increase of DC link current. In equation (13), it is found that; the speed of the synchronous motor mainly depends on the DC link current. This characteristic exactly correlates with that of conventional DC shunt motor.

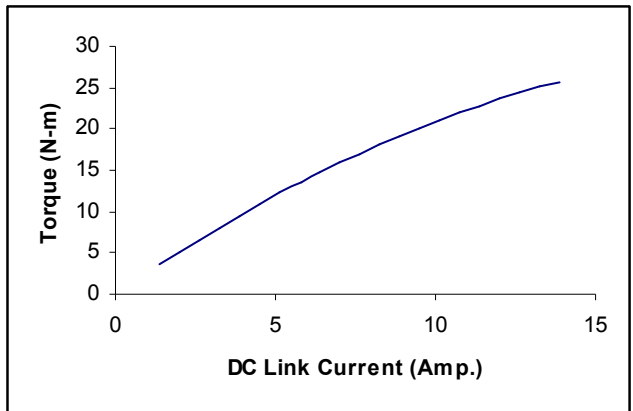


Figure 10: Torque versus DC link current characteristics

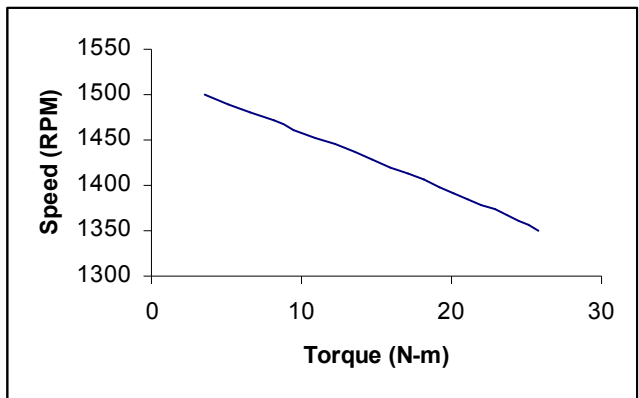


Figure 11: Speed versus torque characteristics

- ii) The variation of machine torque with DC link current is shown in Fig. 10. It is observed from equation (14) that the torque of the machine is proportional to the DC link current. Therefore the torque increases with input current, like a conventional DC shunt motor.

- iii) The variation of machine speed with increase in machine torque is shown in Fig. 11. It can be observed from Fig. 11 that the speed of synchronous machine decreases with torque like a conventional DC shunt motor.

5 CONCLUSIONS

A mathematical model for the steady state performance analysis of the commutatorless DC shunt motor 6 KW, 4 poles commutated DC shunt motor has been computed by a simulation experiment using Fortran Power Station programming. The study of steady state analysis confirms that a synchronous motor with the excitation winding connected in parallel with the inverter input is equivalent to a conventional DC shunt motor. We got the similar results for speed and torque characteristics for all capacities of commutatorless DC shunt motors using the derived steady state general equation. Hence, synchronous motors can be used as variable speed drives in modern industrial applications as commutatorless DC shunt motor.

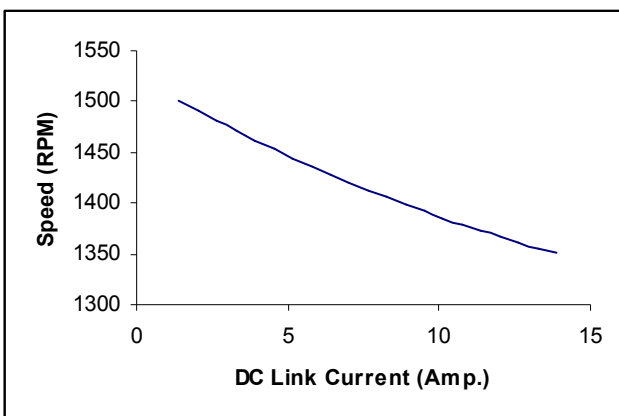


Figure 9 Speed versus DC link current characteristics

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Effect of Different Nonconductive Substrate Materials on a P-Shaped Wearable Antenna

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Abstract-This paper represents the effect of using different nonconductive substrate materials on a P shaped wearable antenna. This P shaped wearable antenna is designed to be used for Body Centric Wireless Communication (BCWC) at 2.45 GHz. Four types of nonconductive materials were selected i.e. glass, marble, polyethylene, rubber. These four types of nonconductive materials are compared with duroid (tm) substrate. The results demonstrated a good agreement between simulated return losses of all four substrates used for wearable antenna. The polyethylene based wearable antenna offered higher return loss compared to other substrate based antenna. The simulated return loss characteristics for all four types of substrates agreed reasonably well with this P shaped wearable antenna. Numerical study has been carried out by using Ansoft HFSS V13 simulating software.

Keywords- Wearable antenna, substrate materials, body centric wireless communication, return loss.

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Manuscript received on 31 July 2013 and accepted for publication on 26 August 2013.

1 INTRODUCTION

NOW-a-days microwave resonators have become very important subject of interest. Recent years have observed the demand for reconfigurable antennas, these are used in a variety of applications, including sensors, filters, frequency meters and tuned amplifier etc [1]. These are commonly used in many commercial applications in the industry, such as mobile satellite communications, direct broadcast satellite services etc. The first wearable active receiving textile antenna operating at 2.45 GHz is addressed for use in personal area networks[2]. Slotted antennas for WLAN applications become a research point in the past decades and many different technologies for miniaturized antenna have been proposed [3]-[6], slotted antennas for ISM band become a hot research point in the past decades and many technologies for miniaturized antenna have been proposed [7].

has been calculated based on transmission line model [8]. The width and length of the patch has also been estimated [9]. The substrate duroid (tm) (dielectric constant 2.2) has been taken in this design. It is also very helpful to understand the interaction and performance of the antenna and the communication system for BCWC.

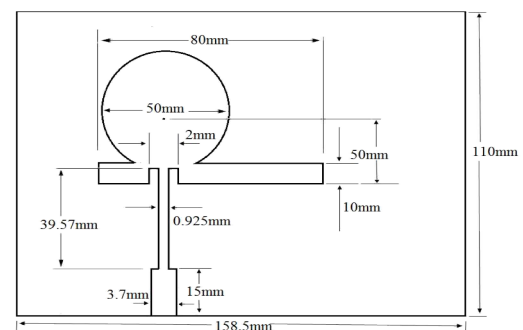


Figure 1: Geometry of the P-shaped micro strip patch antenna.

2 WEARABLE ANTENNA DESIGN

In this paper a new wearable antenna is used for BCWC operating at the frequency 2.45 GHz, as a P shape wearable antenna with micro strip line feed. A numerical study has been done, to find out the exact feed location and the feed location is found at $(-44.59, 1.85, 0)$. Dimension of the patch

BCWC has been given a great attention in recent years due to the advances in wireless technology. Now the advent of textile antennas has opened doors for the emergence of body-worn antenna systems embedded in known as "smart clothes"[10]. Textile antenna is very suitable for on body

radio communication as it is flexible, comfortable to be integrated into clothing[11] and also offers a low cost and easy to manufacture.

3 SIMULATION ENVIRONMENT

This research focuses on the investigation of the effect of different substrates on the performance of a wearable antenna in terms of return loss characteristics. Simulation has been carried out by using Ansoft HFSS V13 simulating software. The performance of the wearable antenna is compared to a conventional duroid(tm) antenna at 2.45 GHz. Four types of nonconductive materials were selected i.e. glass, marble, polyethylene, rubber. The results may be happened due to these materials relative permittivity characteristics. The relative permittivity of duroid (tm), glass, marble, polyethylene, rubber is described below in TABLE 1.

TABLE 1
RELATIVE PERMITTIVITY OF DIFFERENT SUBSTRATE MATERIALS

Substrate Material	Relative Permittivity
Duroid(tm)	2.2
glass	5.5
marble	8.3
polyethylene	2.25
rubber	3

4 RESULTS AND ANALYSIS

TABLE 2 summarizes the comparison of centre frequency between simulated wearable antenna using different substrates. From TABLE 3 and Figure-2, it can be observed that some amount of downward frequency and upward frequency shift occurred with the utilization of different substrates. Rubber based antenna showed the worst upward frequency shifting where the downward shifting of polyethylene is larger than conventional antenna.

TABLE 2
CALCULATED CENTRE FREQUENCY OF DIFFERENT SUBSTRATE MATERIAL BASED ANTENNA

Substrate Material	Centre Frequency
Duroid(tm)	2.325
glass	2.55
marble	2.025
polyethylene	2.25
rubber	2.5

TABLE 3
CALCULATED RETURN LOSS OF DIFFERENT SUBSTRATE MATERIAL BASED ANTENNA

Substrate Material	Return Loss
Duroid(tm)	-17.5
glass	-14
marble	-5.5
polyethylene	-19
rubber	-0.375

From Figure 2, it can be seen that there is a good agreement between poly-ethylene based antenna and conventional antenna. However, polyethylene based antenna produced higher return loss than conventional antenna by 1.5 dB. The other three antenna using glass, marble, and rubber produced 3.5 dB, 12 dB and 17.125 dB lower than conventional antenna respectively. From TABLE 3 the result exhibited that polyethylene based textile antenna produced greater return loss -19 dB. Other three substrates based antennas produced -14 dB, -5.5 dB, -0.375 dB return loss respectively. These results may be happened due to these materials relative permittivity characteristics.

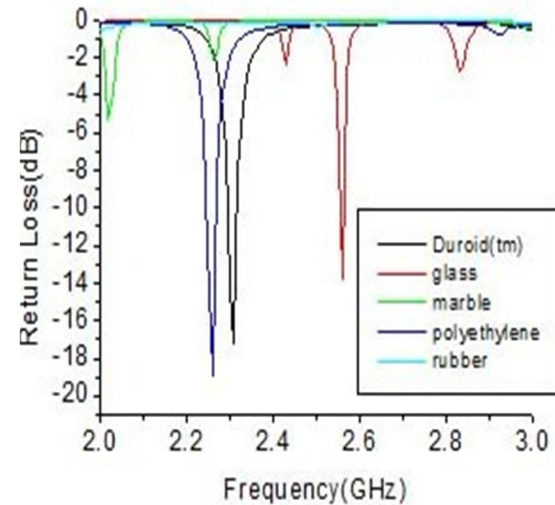


Figure 2: Simulated return loss for different substrate materials based antenna

5 CONCLUSION

The investigation of the effect utilizing four different substrate materials for P shaped wearable antenna is presented in this paper. The return loss characteristics of all five types substrates P shape wearable antennas were studied. The result exhibited that all four substrates (glass, marble, polyethylene and rubber) based P shape wearable antenna are compared to a duroid(tm) based P shaped

wearable antenna. The polyethylene based wearable antenna produced higher return loss compared to other substrates based antenna.

ACKNOWLEDGEMENT

The authors like to acknowledge Dr. B. C. Roy Engineering College, Durgapur, India and Bengal Engineering and Science University (BESU), Shibpur, India for providing necessary support during this research work.

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Prosthetic Arm – its Digital Realization

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Abstract—The technology that deals with the design and construction of prosthetic arm has shown great progress in recent years. The prosthetic arm considered in this article is a substitute of the natural arm and is capable of performing its function. Here two standard arms that are modeled through Recursive Least Squares (RLS) methods considered for processing. The present work is focused on PID tuning and discrete domain analysis which makes it interesting as prosthetic work in digital domain is less. Designing the arms is also concerned with proper realization of control system in terms of related parameters. The optimality of the system is achieved and the design proves its stability. In the design proportional integral and derivative (PID) type of compensation is incorporated appropriately. Discrete digital control design of conceptual hand prosthesis is realized through the work. Here, the system is processed in sample data domain using z-transformation, and it readily accommodates any change of data in system or input parameter. Accordingly Jury test analyzes the system to be stable.

Keywords—Prosthetic arm-RLS design, PID compensation, control parameter analysis Jury stability test.

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Manuscript received on 21 June 2013 and accepted for publication on 22 July 2013.

1 INTRODUCTION

PROSTHETIC limb is an artificial device extension that replaces a missing body part. Normally a limb works as per the commands received from the brain via various neuromotors [1,2,3]. The brain monitors the desired position and the sensed position, generating an error signal to the nervous system [4]. The biological concept is to introduce the robotic arm and to develop its artificial organism with dexterity [2]. The technology is based on prosthetic limb control modeling and analysis through error control system [4]. Here, mathematical models are initiated with two transfer function for two different arms by RLS method. Proper PID tuning is set up for both models. The parametric value from the response analysis is found to be effective for comparison. A stable system holds the set point without oscillating. Thus, satisfactory criteria of stability are established by Jury table representation which is one of the best suited tools in discrete domain [5,6].

2 DESIGN AND SIMULATION ASPECT TOWARDS DISCRETE DOMAIN ARM TRANSFER FUNCTION

2.1 Recursive Least Squares

The arms are modeled mathematically using the Recursive Least Squares method [8] using a program written in Borland C++ Builder. Next discussion gives the overview of the modeling using RLS method. The main advantages of using this system identification method are the factors such as friction are taken into account. A model of the real system is obtained rather than a theoretical one where factors such as friction are ignored. Each of the individual limbs is considered as an independent system and all are controlled simultaneously. It is assumed that they do not affect each other although there is some (small) effect. Various parameters are experimented with in order to obtain the best

model. The changing parameters are the number of poles and zeros.

The poles in the denominator of this model represent its stability. The stability can be represented by their position in the unit circle. The poles of this system are near the imaginary axis of the unit circle. This confirms the oscillatory motion that occurs [16, 17, 18].

If the poles are by the edge of the circle then the system is virtually unstable and oscillations are much more of a factor and take longer to dissipate. The “soft” nature of the springs lessens the effect.

The objective of the controller is to move the poles on to the real axis so that the oscillations are dampened and are not of much effect.

The mathematical model for the first arm that were obtained by the RLS methods was

$$T(z) = C(z)/R(z)$$

$$T(z) = \frac{0.00z + 0.0273}{(-0.7487)z^5 + (-0.2067)z^4 + (-0.5245)z^3 + 0.1424z^2 + 0.06z + 0.3053} \quad \text{.....(i)}$$

The mathematical model for the second arm that were obtained by the RLS methods was

$$T(z) = C(z)/R(z)$$

$$T(z) = \frac{0.0000z^2 + 0.0222z + 0.0143}{z^9 + (-1.8441)z^8 + 0.6365z^7 + 0.5541z^6 + (-0.3747)z^5 + 0.0054z^4 + 0.5070z^3 + (-0.6453)z^2 + 0.0841z + 0.1138} \quad \text{.....(ii)}$$

These models represent the response of each arm to a step input of 45 degrees. The first arm response is very similar to the mathematical model as shown in Fig.1

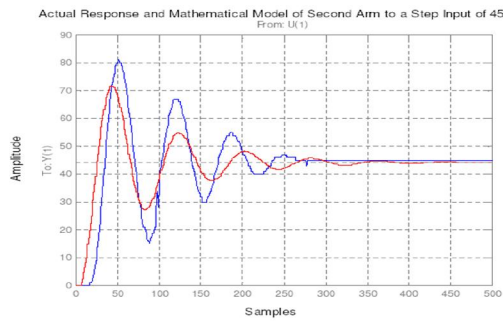


Figure 1. The mathematical model (red) and actual response (blue) of the first arm to a step input of 45.

The model of the second arm is less good due to the speed of response of the arm to a step input of 45. The graph is as follows:

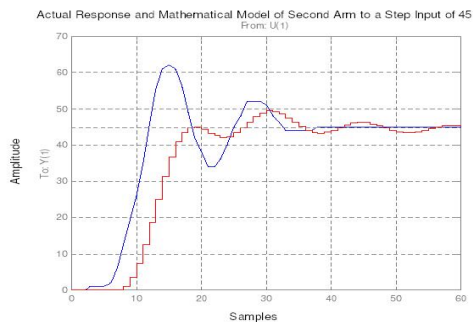


Figure 2. The mathematical model (red) and the actual response (blue) of the second arm to a step input of 45

These models are by no means an exact replica of the actual response of each arm. However they are a good approximation, which will be used to configure the control.

The first arm system is design with six poles and six zeros. The second arm system is design with three poles and nine zeros. These values are realized from experimentation.

2.2 Open-Loop Control Consideration

When a system is without any feedback path, an open loop control is achieved. This type of control causes this arm to move in a ballistic manner and oscillate before a final resting position is achieved. In maximum systems this type of control is of no use.

This type of control is used when the limbs move slowly. The speed of the arm has a direct relationship to the ballistic nature of the arm. If the arms move sufficiently slowly, virtually no recognizable oscillations can be seen, as very little energy is stored in the springs.

2.3 Closed-Loop Control Consideration

Closed loop control has a feedback path, which affects the input and helps in obtaining the desired output. This is the conventional controlling method when for systems such as robotic arms. There are different approaches such as Proportional-Integral-Derivative control and Lead Lag Control [7,9]. Fig.3. shows the block diagram of the system with the controller present. All of the controllers explained subsequently are negative feedback controllers and are implemented into the Controller block [10].

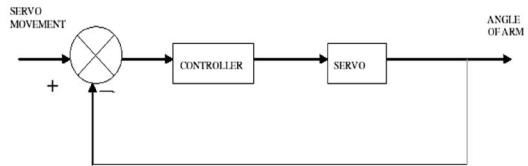


Figure 3. Block Diagram of the Whole System

2.4 Control Action for Proper Gain Tuning

Firstly a variable proportional controller is implemented which deals with different gains within the system.

The input is simply a voltage to the servo and the output is the joint angle. The potentiometer converts the angle to a voltage, which is compared to the desired values [11]. It should be noted that there is also another inner feedback loop within the servo but this is not controlled.

The control loop implemented looks at the size of the error and changes the speed at which the servo is moving accordingly. Greater the difference between the original and desired joint angle, faster the servo will move and vice versa. The user of the C++ program can set the error scalar to investigate different results and hence choose the most appropriate one. The block diagram describing this controller is shown in Fig.4.

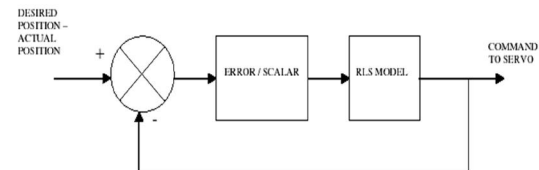


Figure 4. The Block Diagram for PID control

This control method can reduce the oscillations that occur from an un-damped system[12] but not completely, which is due to the nature of the simplicity of the control.

2.5 Proportional-Integral-Derivative (P.I.D.) Imposition for Optimal Response

Subsequently a Proportional-Integral-Derivative (P.I.D.) controller is investigating as a more complicated control strategy. This type of controller is widely used in control systems due to its flexibility. It can be employed to meet many different design needs. For example it can be used to decrease rise time, reduce overshoot and decrease oscillations [13]. This is due to the flexibility of the three sections of the control. That is the proportional, integral and derivative parts. The proportional part can be used to adjust the speed with which the system responds. The integral term provides zero error and the derivative term introduces damping. The derivative term is the important section in this case. The block diagram of the control system with a PID controller is as follows:

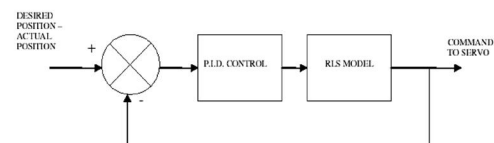


Figure 5. The Block Diagram for PID control

The Ziegler Nichols Tuning Method [14] is used to obtain initial values for the proportional, integral and derivative sections. These values are used as a guide and then tweaked in order to obtain a response that is desired. The response of the first arm with P.I.D control is shown in Fig. 6.

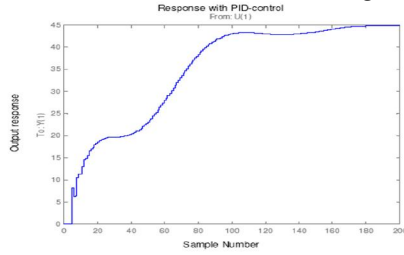


Figure 6. Response of the First Arm with PID Control

Fig. 7. Shows response of the second arm with PID control.

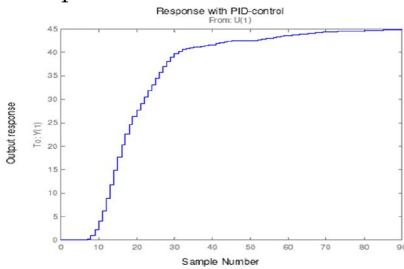


Figure 7. Response of the Second Arm with PID Control

2.6 Lead Lag Compensation Control for the Arm Model

There are various approaches to this method of compensation. The compensation can be cascade, feedback, output or load, or input [9]. The compensation used is cascade. That is the compensation control was placed before the plant. Fig. 8. shows such system.

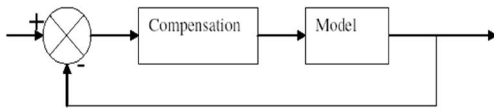


Figure 8. Block Diagram showing cascade compensation

The lead lag compensation is designed using the root locus method. Additional zeros are added to a lead component to cancel out the poles of the model. Then extra poles are added near the centre of the unit circle until a desirable transient response is achieved.

Poles are added near to (0, 0) as the decay time is less nearer to the centre. A lag term is then added to reduce the steady state error. The block diagram for lead lag controller is shown in Fig. 9.

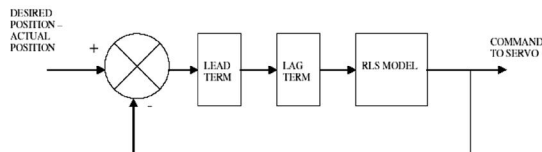


Figure 9. The Block Diagram for Lead Lag control

The simulated response with lead lag control for the first arm and second arm is as follows:

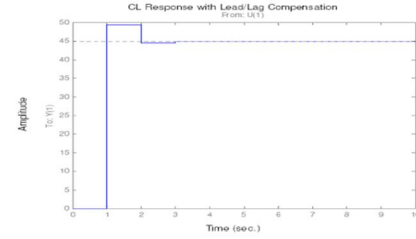


Figure 10. Response of the First Arm with Lead Lag Control

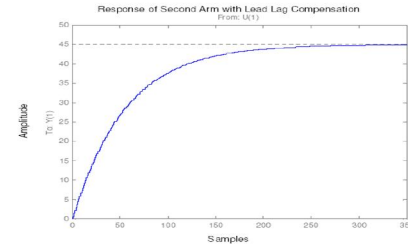


Figure 11. Response of the Second Arm with Lead Lag Control

All three of the control strategies has different characteristics such as complexity, transient response and overshoot. For real world applications however the desired features might be slightly different which would lead to different requirements.

3 RESULT AND TESTING

Various tests are carried out using several control strategies. These are divided into two sections: a comparison section to evaluate the different control strategies and an application section, which experiments with the arm doing real-life applications.

The first test is carried out on the first limb. This is reset to an angle of 45 degrees from the vertical section and will give a step input of 45 degrees to move it to 90 degrees to the vertical, which is repeated for all four control strategies. That is no control (red line); variable gain (green line), PID (blue line) and lead lag compensation (purple line). The figure below show the result of the first limb to this step input under different control strategies.

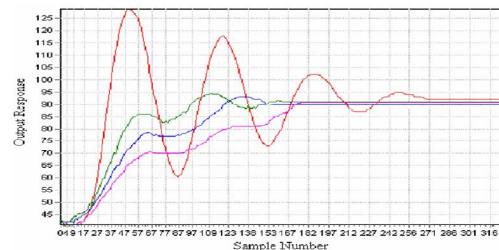


Figure 12. Graph showing the response of the first limb to a 45-degree step input under different control strategies

The table below is the analysis of the graph data above. It shows the different settling times, the steady state error and overshoots percentage values that occur with the different control strategies.

TABLE 1
NUMERICAL ANALYSIS OF THE RESULT OF THE DIFFERENT CONTROL STRATEGIES

Control Method	Steady State Error	Percentage Overshoot	Response Time (s)
Open Loop	+3	81%	4.15
Variable Gain	+2	6.4%	2.46
PID	0	6.6%	2.31
Lead Lag	+1	0%	2.69

As it can be seen for this particular step input to this particular arm the best overall control strategy is PID. This does overshoot however it has a zero steady state error as expected and a fast response time.

The second test on the first arm is a step input with a magnitude of 55 degrees. The start and end positions are also different to the first test. The starting angle from the vertical is 55 degrees and the end angle is 110 degrees. Again all four-control strategies are shown.

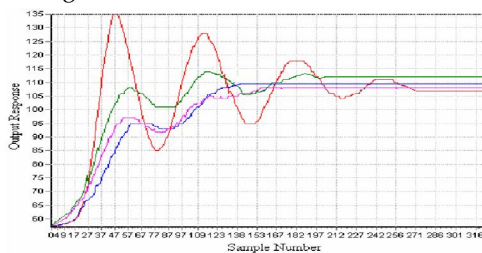


Figure 13. Graph showing the response of the first limb to a 55-degree step input under different control strategies.

The table below numerically analyses the graph data.

TABLE 2
NUMERICAL ANALYSIS OF THE RESPONSE OF THE 55-DEGREE STEP TO THE FIRST LIMB

Control Method	Steady State Error	Percentage Overshoot	Response Time (s)
Open Loop	-3	53.8%	4.16
Variable Gain	+2.5	3.4%	3.15
PID	-0.5	0%	2.12
Lead Lag	-2	0%	2.35

As the table shows the PID is the best control strategy. There is no overshoot but a slight steady state error. The response time is also the quickest of the four control strategies.

Tests are now carried out upon the second limb. The first limb is kept at an angle of 90 degrees to the vertical upright during these. The first test on the second limb involved giving it a 45-degree step input. The starting position is 45 degrees to the first limb and the desired end position was 90 degrees to horizontal first limb; that is vertical. The four control strategies are tested upon and the results are graphically represented below.

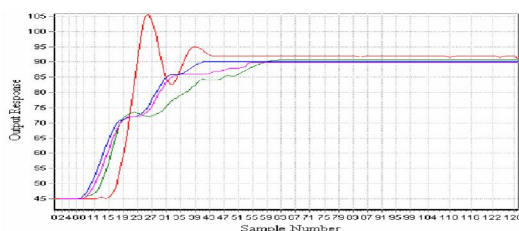


Figure 14. Graph showing the response of the second limb to a 45-degree step input with different control strategies.

A numerical analysis of the graph above is represented in the below table.

TABLE 3
ANALYSIS OF THE RESPONSE OF THE SECOND ARM TO A STEP INPUT OF 45 DEGREES.

Control Method	Steady State Error	Percentage Overshoot	Response Time (s)
Open Loop	+2.5	26.3%	0.66
Variable Gain	+1	0%	0.97
PID	0	0%	0.62
Lead Lag	-0.5	0%	0.83

As the table shows the PID is the best control strategy. There is no steady state error and overshoot and the response time is the quickest of all four-control strategies.

The next test on the second limb is a step of 55-degrees. The starting position of the arm for all four-control strategies is 55-degrees to the first limb and the desired end position is 110 degrees to the horizontal first limb. The response of each control strategy is below. The red line symbolizes the open loop no control strategy. The green line represents the variable gain control. The blue line represents PID control and the purple line represents the lead lag compensation.

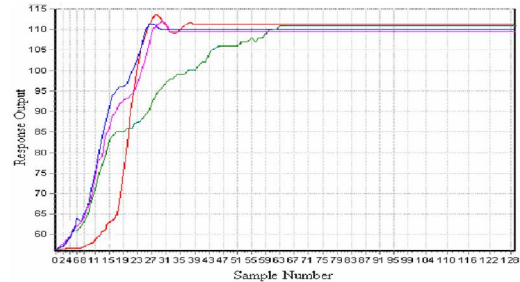


Figure 15. Graph of response to a 55-degree step input of the second limb.

The table below is the numerical analysis of the response of the arm to the 55-degree step input.

TABLE 4
ANALYSIS OF THE RESULT TO A STEP INPUT OF 55-DEGREES TO THE SECOND LIMB

Control Method	Steady State Error	Percentage Overshoot	Response Time (s)
Open Loop	+2	3.5%	0.6
Variable Gain	+1.5	0%	0.97
PID	0	1.8%	0.45
Lead Lag	-0.5	4.6%	0.55

The table above shows that PID control is the best control strategy. There is no overshoot and the response is quickest. However there is a slight overshoot of 1.8% but this is small enough to be ignored and still state that the test is a success. The investigations on the second arm show that PID control is the most successful control strategy. The control is not as important with this limb due to the stiffer springs [15]. This is the reason why in the first test, three of the control strategies have a 0% overshoot. The second test overshoot is much less because the arm is moving upwards and is being acted upon by gravity.

Considering the first arm transfer function

$$T(z) = C(z) / R(z)$$

$$T(z) = \frac{0.00z + 0.0273}{(-0.7487)z^5 + (-0.2067)z^4 + (-0.5245)z^3 + 0.1424z^2 + 0.06z + 0.3053}$$

Characteristic polynomial:

$$F(z) = (-0.7487)z^5 + (-0.2067)z^4 + (-0.5245)z^3 + 0.1424z^2 + 0.06z + 0.3053$$

$$F(1) = -0.9722 [F(1) < 0 \text{ not satisfied}]$$

$$(-1)^5 F(-1) = -1.4542 [(-1)^4 F(-1) < 0 \text{ not satisfied}]$$

TABLE 5
JURY TEST FOR FIRST ARM TRANSFER FUNCTION

Row	z^0	z^1	z^2	z^3	z^4	z^5
1	$a_0 = 0.3053$	$a_1 = 0.06$	$a_2 = 0.1424$	$a_3 = -0.5245$	$a_4 = -0.2067$	$a_5 = -0.7487$
2	$a_5 = -0.7487$	$a_4 = -0.2067$	$a_3 = -0.5245$	$a_2 = 0.1424$	$a_1 = 0.06$	$a_0 = 0.3053$
3	$b_0 = -0.46734$	$b_1 = -0.13643$	$b_2 = -0.34922$	$b_3 = 0.05351$	$b_4 = 0.01819$	
4	$b_4 = 0.01819$	$b_3 = 0.05351$	$b_2 = -0.34922$	$b_1 = -0.13643$	$b_0 = -0.46734$	
5	$c_0 = 0.21807$	$c_1 = 0.06279$	$c_2 = 0.15685$	$c_3 = 0.02253$		
6	$c_3 = 0.02253$	$c_2 = 0.15685$	$c_1 = 0.06279$	$c_0 = 0.21807$		
7	$d_0 = 0.04704$	$d_1 = 0.01016$	$d_2 = 0.03279$			

$$b_k = \begin{vmatrix} a_0 & a_{n-k} \\ a_n & a_k \end{vmatrix} \quad c_k = \begin{vmatrix} b_0 & b_{n-1-k} \\ b_{n-1} & b_k \end{vmatrix} \quad d_k = \begin{vmatrix} c_0 & c_{n-2-k} \\ c_{n-2} & c_k \end{vmatrix}$$

TABLE 6
JURY TEST FOR SECOND ARM TRANSFER FUNCTION

Control Method	Steady State Error	Percentage Overshoot	Response Time (s)
Open Loop	+2	3.5%	0.6
Variable Gain	+1.5	0%	0.97
PID	0	1.8%	0.45
Lead Lag	-0.5	4.6%	0.55

Row	z^0	z^1	z^2	z^3	z^4	z^5	z^6	z^7	z^8	z^9
1	$a_0 = 0.1138$	$a_1 = 0.0841$	$a_2 = -0.6453$	$a_3 = 0.5070$	$a_4 = 0.0054$	$a_5 = -0.3747$	$a_6 = 0.5541$	$a_7 = 0.6365$	$a_8 = -1.8441$	$a_9 = 1$
2	$a_9 = 1$	$a_8 = -1.8441$	$a_7 = 0.6365$	$a_6 = 0.5541$	$a_5 = -0.3747$	$a_4 = 0.0054$	$a_3 = 0.5070$	$a_2 = -0.6453$	$a_1 = 0.0841$	$a_0 = 0.1138$
3	$b_0 = -0.9870$	$b_1 = 1.8537$	$b_2 = -0.7099$	$b_3 = -0.4964$	$b_4 = 0.3753$	$b_5 = -0.0480$	$b_6 = -0.4439$	$b_7 = 0.7177$	$b_8 = -0.2939$	
4	$b_8 = -0.299$	$b_7 = 0.7177$	$b_6 = -0.4439$	$b_5 = -0.0480$	$b_4 = 0.3753$	$b_3 = -0.4964$	$b_2 = -0.7099$	$b_1 = 1.8537$	$b_0 = -0.9870$	
5	$c_0 = 0.8878$	$c_1 = -1.6187$	$c_2 = 0.5702$	$c_3 = 0.4758$	$c_4 = -0.2601$	$c_5 = -0.0985$	$c_6 = 0.2295$	$c_7 = -0.1635$		
6	$c_7 = -0.1635$	$c_6 = 0.2295$	$c_5 = -0.0985$	$c_4 = -0.2601$	$c_3 = 0.4758$	$c_2 = 0.5702$	$c_1 = -1.6187$	$c_0 = 0.8878$		
7	$d_0 = 0.7614$	$d_1 = -1.3995$	$d_2 = 0.4901$	$d_3 = 0.3799$	$d_4 = -0.1531$	$d_5 = 0.0058$	$d_6 = -0.0611$			
8	$d_6 = -0.0611$	$d_5 = 0.0058$	$d_4 = -0.1531$	$d_3 = 0.3799$	$d_2 = 0.4901$	$d_1 = -1.3995$	$d_0 = 0.7614$			
9	$e_0 = 0.5759$	$e_1 = -1.0652$	$e_2 = 0.3638$	$e_3 = 0.3125$	$e_4 = -0.0866$	$e_5 = -0.0811$				
10	$e_5 = -0.0811$	$e_4 = -0.0866$	$e_3 = 0.3125$	$e_2 = 0.3638$	$e_1 = -1.0652$	$e_0 = 0.5759$				
11	$f_0 = 0.3251$	$f_1 = -0.6205$	$f_2 = 0.2349$	$f_3 = 0.2095$	$f_4 = -0.1363$					
12	$f_4 = -0.1363$	$f_3 = 0.2095$	$f_2 = 0.2349$	$f_1 = -0.6205$	$f_0 = 0.3251$					
13	$g_0 = 0.0871$	$g_1 = -0.1732$	$g_2 = 0.1084$	$g_3 = -0.0165$						
14	$g_3 = -0.0165$	$g_2 = 0.1084$	$g_1 = -0.1732$	$g_0 = 0.0871$						
15	$h_0 = 0.073$	$h_1 = -0.0133$	$h_2 = 0.0066$							

$$b_k = \begin{bmatrix} a_0 & a_{n-k} \\ a_n & a_k \end{bmatrix}$$

$$d_k = \begin{bmatrix} c_0 & c_{n-2-k} \\ c_{n-2} & c_k \end{bmatrix} \quad e_k = \begin{bmatrix} d_0 & d_{n-3-k} \\ d_{n-3} & d_k \end{bmatrix}$$

$$f_k = \begin{bmatrix} e_0 & e_{n-4-k} \\ e_{n-4} & e_k \end{bmatrix} \quad g_k = \begin{bmatrix} f_0 & f_{n-5-k} \\ f_{n-5} & f_k \end{bmatrix}$$

$$h_k = \begin{bmatrix} g_0 & g_{n-6-k} \\ g_{n-6} & g_k \end{bmatrix}$$

Now considering the second arm transfer function

$$T(z) = C(z)/R(z)$$

$$T(z) = \frac{0.0000z^2 + 0.0222z + 0.0143}{z^9 + (-1.8441)z^8 + 0.6365z^7 + 0.5541z^6 + (-0.3747)z^5 + 0.0054z^4 + 0.5070z^3 + (-0.6453)z^2 + 0.0841z + 0.1138}$$

Characteristic polynomial:

$$F(z) = z^9 + (-1.8441)z^8 + 0.6365z^7 + 0.5541z^6 + (-0.3747)z^5 + 0.0054z^4 + 0.5070z^3 + (-0.6453)z^2 + 0.0841z + 0.1138$$

$$F(1) = 0.0368 [F(1) > 0 \text{ satisfied}]$$

$$(-1)^4 F(-1) = 3.669 [(-1)^4 F(-1) > 0 \text{ satisfied}]$$

Sufficient conditions for stability are

$$[a_0] < [a_9], \text{ Satisfied}; [b_0] > [b_8], \text{ Satisfied}$$

$$[c_0] > [c_7], \text{ Satisfied}; [d_0] > [d_6], \text{ Satisfied}$$

$$[e_0] > [e_5], \text{ Satisfied}; [f_0] > [f_4], \text{ Satisfied}$$

$$[g_0] > [g_3], \text{ Satisfied}; [h_0] > [h_2], \text{ Satisfied}$$

The required conditions are satisfied. Hence, the second arm transfer function is stable.

Table 5 represents the Jury format of first Arm Transfer function. From Table 5 the sufficient conditions for stability are obtained.

$$\begin{aligned} |a_0| &< |a_5|, \text{ Satisfied} \\ |b_0| &> |b_4|, \text{ Satisfied} \\ |c_0| &> |c_3|, \text{ Satisfied} \\ |d_0| &> |d_2|, \text{ Satisfied} \end{aligned}$$

So the first transfer function is appropriate for the system.

4 CONCLUSION

It is confirmed that both the prosthetic arms are able with the best control strategy but the second one is more acceptable in every aspect in terms of analysis. Appropriate PID tuning makes the system responses and parameters more adaptable. Analysis through RLS is already established. In future research, advance computational process like particle swarm optimization (PSO), bacterial foraging (BF), fuzzy logic, genetic algorithm (GA) will be incorporated in the study. Basically the biological systems are nonlinear

and non-deterministic in nature. So, the z domain representation of the transfer function will also develop the nondeterministic and nonlinear performance analysis of the arm system. Controllability and observability testing can also be introduced for further analysis of the system.

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An Epistemological Decision Making Framework for Fault Diagnosis

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Abstract— All systems known in nature can malfunction and fail due to faults in their components. Moreover, the growing complexity of industrial plants has also resulted in serious problems in process control which cannot be easily handled by operators. These abnormal events have significant economic and environmental impact. Thus, fault diagnosis has become increasingly important in recent years for the improvement of reliability, safety and efficiency of technical processes. This work attempts to make detailed investigations on Fault diagnosis for a Complex Benchmark Process Control System.

Keywords— Complex Systems, Epistemological Decision Making, Fault Diagnosis

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Manuscript received on 14 August 2013 and accepted for publication on 8 September 2013.

1 INTRODUCTION

NATURAL growth and technological advances have led to development of physical, biological and engineering systems with increasing size and functionality along with increasing demands on their performance. Hence, such systems have increased complexity and enhanced potential to fail, despite safe designs and improved quality control techniques. Thus, system failures have become unavoidable and a growing area of concern.

Further, the growing complexity of industrial plants, such as chemical, petrochemical, sugar and power etc, has also resulted in serious problems in process control which cannot be easily handled by operators. Industrial statistics show that about 70% of the industrial accidents are caused by human errors [1]. These abnormal events have significant economic and environmental impact. Thus, system failures are inevitable in today's complex industrial environment and there is apparent need for effective means of detecting them, due to their impact not only on the systems involved but on the society as a whole. As a result, there has been an increasing interest in fault diagnosis in recent years.

In industrial installations faults may occur in sensors, actuators, components of the controlled process, or within the hardware or/and software of automatic control systems. Moreover, faults in a component may develop into failure of the entire system. This situation can be handled by timely fault isolation followed by repair. Intelligent decision making for early diagnosis of faults is hence the first step to achieve effective automation. Therefore, it can be concluded that intelligent decision making has become the most important issue in operation and control of complex systems. During the last two and half decades,

a large amount of research has been conducted in this field and a variety of methods have been proposed [2].

Early automation systems were based on a simple limit and trend value check. These were followed by the methods based on non-parametric signal analysis, e.g. auto-correlation functions, spectrum analysis etc. But these methods do not allow an in-depth fault diagnosis and do not simulate the human reasoning activity. Most of these methods require special sensors which increase costs and maintenance effort. Further, they require extensive experimentation and data acquisition, which is a difficult task in complex systems. Therefore, modern methods, which rely heavily on simulative analysis, have been developed in the recent years[3].

2 NEED FOR EPISTEMOLOGICAL DECISION-MAKING

The dominant paradigm for decision-making in any field is rational selection of a policy that achieves greatest preference within practical limits of time and resources. Thus, optimal control, optimal estimation, and optimal detection all stem from the common heritage of maximizing utility. When employing such a strategy, however, it must be assured that the criterion used for optimality is above controversy, and that there is sufficient modeling information available to operate the decision rule reliably.

Thus, the following two basic assumptions must be satisfied:-

- First, a best solution must exist.

- Second, there must be sufficient information, time, and resources to find it.

Meystel has named problems that meet these criteria "well-formed problems" [4]. Conversely, an ill-formed problem does not have a unique or well-defined notion of best, or insufficient information, time, or resources. The general knowledge based decision making system starts exhibiting a sudden performance degradation near or beyond the limits of its domain knowledge. Moreover, the decision making system is not able to generate satisfactory explanations, since it can only show the pragmatic constructs composing its own knowledge base. In addition, it may not solve novel problems that the designer did not anticipate while building the system. Finally, there may be several difficulties in acquiring and maintaining knowledge bases, because the systems need the heuristic insight of a domain expert more than mere domain knowledge.

Solutions for these problems may be achieved through a suitable design of the conceptual architecture before starting any implementation activity. This level of design is called knowledge level or epistemological level and the resulting system is epistemological decision making system.

These Challenges to decision making in ill-formed and complex systems make their operation and control extremely difficult. The limitations of decision making systems are further brought into the limelight when the plants they control or operate are susceptible to faults. In such cases the decisions may often go wrong or may be too late to prevent damage to the plant. Several new techniques in the area of computer based control have been developed and are being applied in the modern industrial plants. They are extremely efficient when dealing with a variety of operating conditions in the plant but often turn out to be severely limited in their scope when dealing with unforeseen and fault conditions, as is evident from the conversion of minor faults that are not properly catered into major catastrophes.

It is unfortunate that despite all advances in computer-based control of industrial plants, the fact that two of the worst ever chemical plant accidents [5], namely union carbide's gas tragedy at Bhopal, India and occidental petroleum's piper alpha accident have occurred and caused widespread loss of life and property. Another major incident is the explosion that occurred at the Kuwait Petrochemical's Mina Al-Ahmedi refinery in June 2000, which resulted in about 100 million dollars in damages. More recently, in November 2009 a major fire accident in Indian oil corporation fuel depot at Sitapura in Jaipur has resulted in an economic loss of about Rs 500 crore and in March 2011, fire in six nuclear reactors at Fukushima nuclear-power complexes in Japan after an earthquake have caused huge loss of life and property.

Further, industrial statistics have shown that even though major catastrophes and disasters from plant failures may

be infrequent, minor accidents are very common, occurring on a day to day basis, resulting in many occupational injuries, illnesses and incurring large costs to the society every year [6]. It is estimated that the petrochemical industry alone in the US incurs approximately 20 billion dollars in annual losses due to poor abnormal event management [7]. The cost is much more when one includes similar situations in other industries such as pharmaceutical, specialty chemicals, power and so on. Similar accidents cost [8] the British economy up to 27 billion dollars every year and the Indian economy about 13.8 billion dollars every year.

Thus, prevention of catastrophic failures is the greatest challenge for control engineers. In the past, the regulatory control was automated using computers and thereby removing it from the hands of human operators. This has led to great progress in product quality and consistency, process safety and process efficiency. The current challenge is the automation of fault diagnosis and management using intelligent control systems, thereby providing human operators the assistance in this most pressing area of need. People in the process industries view this as the next major milestone in control systems research and application.

A sincere attempt has been made here to devise an appropriate technique for fault diagnosis of complex systems.

3 DESIRABLE CHARACTERISTICS OF A FAULT DIAGNOSTIC CLASSIFIER

Whenever an abnormality occurs in a process, a general diagnostic classifier would provide a set of hypotheses or faults that explains it. Thus, the desirable characteristics of a fault diagnostic classifier are:-

- Early detection and diagnosis
- Isolability
- Robustness
- Novelty indentifiability
- Multiple fault identification ability
- Explanation facility
- Adaptability
- Reasonable storage and computational requirement.

Completeness of a diagnostic classifier would require the actual fault(s) to be a subset of the proposed fault set. Resolution of a diagnostic classifier would require the fault set to be as minimal as possible. Thus, there is a trade-off between completeness, resolution and accuracy of predictions.

4 GENERAL INTELLIGENT CONTROL AND FAULT DIAGNOSIS FRAMEWORK

Figure 1 depicts the components of a general intelligent control and fault diagnosis framework. It shows a con-

trolled process system and indicates the different sources of failures in it.

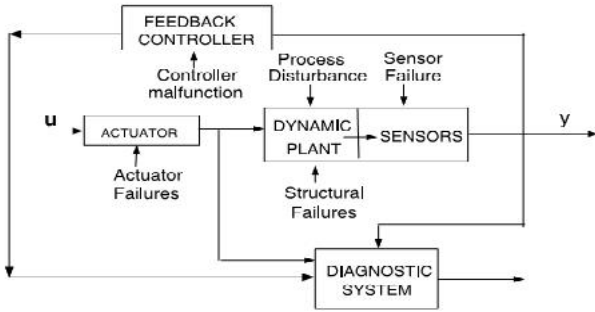


Figure 1: General Intelligent Control and Fault Diagnosis Framework [1]

In general, one has to deal with three classes of failures or malfunctions as described below:

4.1 Process Disturbances and Gross Parameter Changes in a Model

In any modeling, there are processes occurring below the selected level of detail of the model. These processes which are not modeled are typically lumped as parameters and these include interactions across the system boundary. Parameter failures arise when there is a disturbance entering the process from the environment through one or more exogenous (independent) variables.

4.2 Structural Changes

Structural changes refer to changes in the process itself. They occur due to hard failures in equipment. Structural malfunctions result in a change in the information flow between various variables. To handle such a failure in a diagnostic system would require the removal of the appropriate model equations and restructuring the other equations in order to describe the current situation of the process.

4.3 Malfunctioning Sensors, Controllers and Actuators

Errors usually occur with actuators, controllers and sensors due to a fixed failure, a constant bias (positive or negative) or an out-of range failure. A failure in one of the associated equipments could cause the plant state variables to deviate beyond acceptable limits unless the failure is detected promptly and corrective actions are accomplished in time. It is the purpose of diagnosis to quickly detect any equipment failure which could seriously degrade the performance of the control system.

5 EPISTEMOLOGICAL DECISION-MAKING FOR FAULT DIAGNOSIS

Typically, a diagnostic problem starts with the observation of some behavior which is recognized as a deviation

from the expected or desirable, i.e., a malfunction behavior or fault is observed. There are several dimensions of diagnostic strategies and information. The key idea is that the basic knowledge used and its organization leads to the strategies which can be employed. By focusing on different levels of knowledge representation or epistemological considerations, different diagnostic systems can be developed.

Since the task of diagnosis as a classification problem, the diagnostic system is also referred to as a diagnostic classifier. It is important to identify the various transformations that process measurements go through before the final diagnostic decision is made. In general, one can view the diagnostic decision-making process as a series of transformations or mappings on process measurements. Figure 2 shows the various transformations that process data go through during diagnosis.

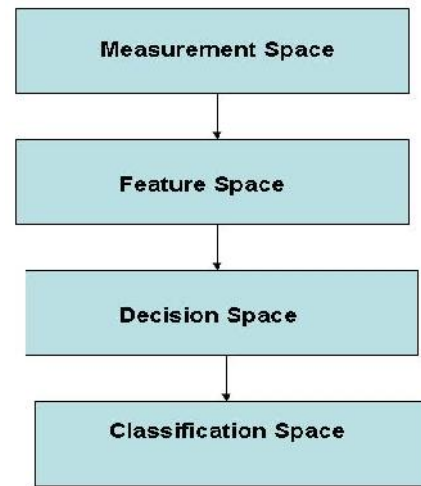


Figure 2: Transformations in a Diagnostic System

The measurement space is a space of measurements with no a priori problem knowledge relating these measurements. These are the inputs to the diagnostic system. The feature space is obtained as a function of the measurements by utilizing a priori problem knowledge. Here, the measurements are analyzed and combined using a priori process knowledge to extract useful features about the process behavior to aid diagnosis.

There are two ways of developing the feature space from the measurement space, namely,

- Feature selection and
- Feature extraction.

In feature selection, a few important measurements of the original measurement space are selected. Feature extraction is a procedure that facilitates, through the use of prior knowledge of the problem, a transformation of the measurement space into a space of fewer dimensions. For example, if a relationship is known to exist between the samples of one measurement and the samples of another measurement, feature extraction is concerned with identi-

fying this relationship to represent them with a single set of parameters.

The mapping from the feature space to decision space is usually designated to meet some objective function (such as minimizing the misclassification). This transformation is achieved by either using a discriminant function or in some cases using simple threshold functions. The decision space is obtained by suitable transformations of the feature space. The class space is a set of integers, indexing the failure classes to indicate their category. The classification space is thus the final interpretation of the diagnostic system. The transformations from decision space to classification space are performed using threshold functions, template matching or symbolic reasoning as the case may be.

6. PRACTICAL APPLICATION

A detailed field study of sugar production process was carried out as a part of this research to identify various factors that affect the quality of sugar, existing control methods and its effect on final product. A sample data sheet of Rajasthan State Ganganagar Sugar Mills Ltd., Sriganganagar (India) for the Cane Crushing Season 2010-11 has been studied [9]. On study of the production data, it may be observed that the percentage of unproductive time for the duration ranging from 06.01.2011 to 15.03.2011 is 20.9%. In all, 342 hours 55 minutes were lost due to Stoppages on account of various reasons, in which Mechanical and Electrical faults share major part of 235 hours. These stoppages not only cause production loss but also have a significant adverse effect on the quality of production of entire batch in progress. Thus, ultimately faults incur a huge monetary loss to the plant.

As the sugar plants are seasonal and operate for a limited period of 3 to 4 months in a year, the faults conditions and their duration become a cause of major concern. The complex nature of production process demands high level of expertise, intelligence and knowledge for diagnosing the possible faults and for improving the productivity and quality of final product.

In view of the analysis mentioned above, it can be concluded that sugar plants are a suitable example of complex systems and favorable for a case study. The research work here has focused on the fault diagnosis in evaporator section of a sugar plant due its direct relationship with the quality and quantity of the final product. The major source of faults in this section results from malfunctioning of electro-pneumatic actuators.

The sugar factory investigations have shown that electro-pneumatic actuators employed in evaporator section have sufficient complexity to warrant detailed diagnostic study. It suffers from a variety of faults ranging from abrupt loss of signals to incipient mechanical failures. The study has shown that by simultaneous monitoring of several actuators and conditions of system operation, it is

feasible to develop powerful diagnosis and supervision tools for the overall process under investigation. The likelihood that actuator systems (e.g. control valves, servomotors, positioners) will malfunction is significant when these components are installed in harsh environments (e.g. with high temperature, humidity, pollution, chemical solvents, aggressive media, etc.).

The identification of the development of small or incipient faults before they become serious, has an important influence on the predicted lifetime of an industrial actuator. Valve faults causing process disturbance and shutdown are of major economic concern and can sometimes be an issue of safety and environmental pollution. Furthermore, when actuators do not function correctly, the final product quality is influenced. The monitoring of the development of incipient faults is therefore an issue not only for predicting maintenance schedules but also for monitoring the performance of the process under study. Thus, fault diagnosis of electro-pneumatic actuator in evaporator section of a sugar plant, is an appropriate example of complex, dynamic and nonlinear industrial problems.

Complex systems often demand distributed decision making at several stages. Therefore, it is aimed to develop a methodology which may help in fast decision making at preliminary level and accurate decision making at secondary level. Thus, the fault cases which can be detected by perception should be handled at abstraction phase of decision making (i.e. Primary Decision Making System) without much computational effort. The correctness of fault detection at primary stage is ascertained by a Secondary Decision Making System that can detect the erroneously unreported fault cases using trends. This double checking process is essential for ensuring the safety of the system by timely detection of the fault at the initial stage. Apart from separating normal operation from fault cases, it is desired that Secondary Decision Making System may further segregate the fault cases depending upon their nature i.e. faults whose symptoms manifest suddenly i.e., Abrupt Faults, or faults whose symptoms grow gradually i.e., Incipient Faults.

Further, it is desirable to develop a suitable methodology for Intra-Class separation of various types of abrupt and incipient faults. Since the thrust of this research work is to base the fault diagnosis decision on deep insight of the process, hence an attempt will be made to select and utilize the best possible epistemic tools and techniques for this purpose.

Finally, for arriving at rational decision; the decision making system should be able to perform epistemological evaluation of adopted policy on the basis of the results from earlier stages of fault diagnosis. On the basis of this evaluation, decision making system should be able to choose its existing policy or adopt alternative policy for decision making. By virtue of this continuous learning, the targeted decision making system will be self learning and intelligent, i.e., it will learn autonomously from real

time experience and further fine tune the decision making system for the continuous improvement in results. The proposed methodology would be validated on benchmark problem and applied to real industrial data. A Graphic User Interface (GUI) developed in MATLAB® according to above methodology has been shown in Figure 3. It has options for receiving data both from the actual plant and the Simulink model.

In addition to providing complete Fault Diagnosis, this GUI can be used for fast modular decision making, when partial knowledge regarding the fault is available. Thus, if the fault class is already known, then the relevant module can be used directly for decision making. For example, in the abrupt fault case, decision making using Statistical, Machine Learning and Neural Network Approaches can be used directly.

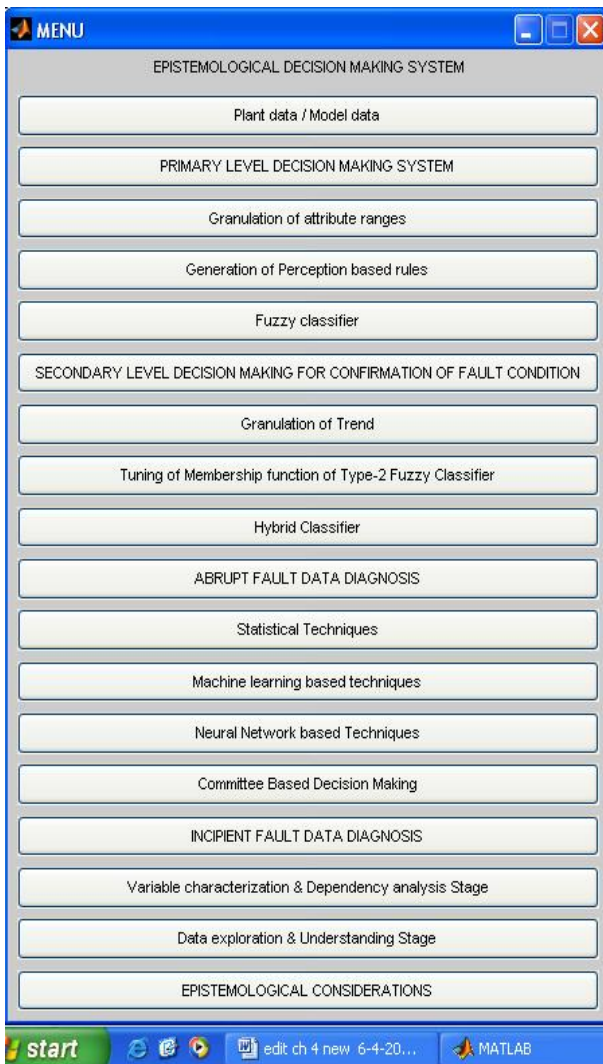


Figure 3: GUI Developed for Proposed Methodology

It is expected that the proposed methodology will overcome the limitations of conventional control methods for complex problems. The efficacy of the proposed methodology has been depicted by considering the problem of

fault diagnosis in actuator employed in evaporator section of a sugar plant.

7 CONCLUSION

On taking holistic view it may be inferred that fault diagnosis involves epistemological decision-making process. Therefore, author has chosen to make detailed investigations on epistemological decision making for fault diagnosis for a complex benchmark process control system.

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Long Term Evolution (LTE): Next Generation Wireless Communication of NASA for Satellite Engineering

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Abstract—This research work is anticipated for verifying the implementation of Long Term Evolution (LTE) over satellite in forward link for the next generation communication of NASA for satellite engineering or extraterrestrial purposes. Recent developments in wireless communication such as MIMO technique that allow improving the received signal quality and capacity, in combination with OFDM makes the signals more robust against delay spread in frequency selective channel. A dual satellite Orthogonal Frequency Division Multiplexing and Multiple-Input and Multiple-Output (OFDM-MIMO) model is considered which provides a handy and robust resource over satellite channel for this purpose. It is OFDM in aggregation to Quadrature Phase Shift Keying (QPSK) with Turbo Coding using 2x2 MIMO as specified for LTE 5 MHz BW, transmitted with satellite power delay profile has analyzed in terms of Bit Error Rate (BER). Spatial multiplexing and diversity are the two features that MIMO provides which has also been investigated. The investigation has been conducted considering downlink transmission over satellite forward link over dual-satellite 2x2 MIMO channel.

Keywords—Wireless System; LTE; MIMO; QPSK; OFDM; Space Coding; Dual Satellite Channel

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Manuscript received on 18 August 2013 and accepted for publication on 8 September 2013.

1 INTRODUCTION

THE National Aeronautics and Space Administration (NASA) is set to launch Data Relay Satellite K (TDRS-K) which is LTE technology over satellite. However, first TDRS satellite launched in 1983. But recent activities of "curiosity" (Curiosity is a car-sized rover exploring on Mars) in Mars has brought concentration of researchers in this arena.

In terrestrial wireless communication, MIMO has demonstrated significant results. But as far as satellite channels are concerned it is not as straight forward as terrestrial. Satellite channels rarely produce independent delay profiles required for MIMO concept to work. It is dominated by LOS (Line of Sight), higher FSL (Free Space Loss). However, we can improvise in order to create different fading channels for satellite. Single satellite having similar delay profile would not help in having a condition for MIMO. Having multiple antennas in single satellite will not produce different fading channels. Due to correlation, two antennas in same satellite will appear to be single satellite [1].

Multiple satellites can be deployed in orbits and separated by a large distance in order to have sufficient correlation and different fading path for achieving diversity. Satellites in different orbits can also be used for creating diversity. Multiple ground station with single satellite would not be convenient as the distance for correlation would be very long extending hundreds of kilometers. But, polarization diversity achieved by using single satellite is remarkable. So far this concept has been successfully implemented over L-band [2]. The only problem is that it does not work in higher frequencies. So, in this project

multiple satellite channels with 2x2 MIMO-OFDM configurations has been investigated in terms of BER and compared with traditional satellite channel capacity [3].

To start this research project, initially concept over MIMO (Multiple Input Multiple Output) is reviewed and found how it works to see various diversity offered by it followed by OFDM (Orthogonal Frequency Division Multiplexing) and see how it is a blessing for us in wireless communication. MIMO and OFDM together make a combined technology to support each other and deliver the maximum throughput which will be discussed next sections. Knowledge about schemes such as binary-phase shift keying (BPSK), QPSK will be gathered provided the addition of OFDM to them. Having a look at different channels (AWGN, Raleigh) is worthy as well. Finally, results are comprised of the simulation of BPSK and QPSK modulation over both AWGN channel and Raleigh channel which are compared in terms of BER against theoretical values. Concluding remarks with future direction have been represented at the end of this paper.

2 LITERATURE REVIEW

2.1 Satellite orbits, Constellations and systems

Single satellite can provide a limited service to a limited location. If we are to provide a larger global coverage then it is worth considering satellite constellations. A satellite constellation is a cluster of satellite system working together for a specific purpose or service. Generally the constellations are deployed in three different orbits based on their

requirement. The three categories of orbits are GEO, MEO and LEO.

The orbit period for GEO constellations is 23 hour and 56 minutes and 4 second and deployed to a height of 35 786 km. Therefore the satellites in GEO constellations revolve eastward from the earth and seem to be immobile from the earth. GEO satellites are very popular for services such as Direct TV or VSAT. One example of GEO satellite system is INMARSAT-3 which is used for portable mobile telephony. To find out more about INMARSAT-3 characteristic [10] can be referred.

One of the key problems with GEO satellite is long delay in signal propagation. LEO satellite constellations are used to tackle the problems for mobile satellite systems. LEO system reduces the round trip delay to few milliseconds. The altitude for this system ranges from 700-1500 km. However, due to lower altitude the satellite in LEO can cover less area. For covering larger area, more satellites are required. Also for proper function requires inter satellite links and complex on board processing. Global star is a simple satellite system in LEO for cellular networks. The system utilizes 48 satellites for a service in dual mode for real-time data transfer, paging and voice. The multiple-satellite concept is used in this system for achieving satellite diversity. Iridium also uses LEO system and uses inter satellite links and on board processing. It has a constellation of 66 satellites [6].

For satellite services which require certain parameters in between GEO and LEO, there is an intermediate orbit called MEO. The altitude for the orbit ranges from 5000 to 7000 km and capable of covering the globe with only 10-15 satellites. Advantages of both LEO and GEO converge in MEO.

2.2 Long Term Evolution(LTE):

In order to meet the demand and develop a promising solution over existing system in wireless system, LTE has evolved. It is a 4G technology and 3GPP standard that exploit the latest advances in physical layer technologies comprising OFDM, MIMO, OFDMA, SC-FDMA etc. These sophisticated methods allow very highly features for LTE. For example, with minimum 2x2 MIMO configurations it provides an uplink speed up to 50 Mbps and downlink speed up to 100 Mbps along with lower latency and scalable bandwidth. Beside physical layer developments, flat IP architecture for LTE provides a simplified and effective network. LTE, upon deployment over satellite keeps the ability to have major impact over global communication systems [4,5].

2.3 Multiple input and multiple output (MIMO):

Traditionally SISO (Single Input and Single Output) systems are used in wireless communication systems. The disadvantage of SISO systems is that we cannot increase the capacity unless more spectrum or transmit power is used. There are three categories of MIMOs which is shown in table 1.

Using more antennas for communication systems instead of a pair of them provides multiple channels with different fading for information signal to travel. If the receiving antennas are able to get a signal with enough strength from any of these channels then it can easily retrieve the information signal. If the fading channels are independent of each other then chances of recovering the signal is very high [6, 7].

To get a clear perception of MIMO Functions, we need to know different usages of MIMO. They are as follows: MIMO can be used in different ways

- a. Pre-coding is the process where same signal transmitted from different antennas in such a way that at the receiver end a particular antenna will experience maximum gain. This process not only helps in getting increased gain at the receiver but also combats multipath fading. Pre-coding is used in the scattering environment where using multiple antennas may not provide the same signal strength at all receiver. Therefore prior knowledge about the channel is also required in the process.
- b. Frequency diversity or Spatial multiplexing is used for interleaving group of fragmented low data rate frequencies from a high data rate frequency and transmit them over the channel after which they are de-multiplexed at the receiver to get the higher data rate. More the number of antennas more are the number of channels and more data streams allowable to be sent leading to higher data rate.
- c. Spatial diversity is where antennas have to be separated by sufficient space achieving low correlation of different channels in order to achieve diversity in space domain.

For large number of antennas in MIMO system

$$M_T = M_R > 1$$

$$C \log_2 \rightarrow \det[I_M + \left(\frac{Y}{M_T}\right) I_R] = M_R \log_2 \left(1 + \frac{Y}{M_T}\right) \dots (1)$$

The capacity of MIMO system increases linearly with the number of transmit-receive antennas.

2.4 Orthogonal Frequency Division Multiplexing (OFDM)

We know the fact that in wireless communication, frequency selective fading is successfully mitigated by using the OFDM (Orthogonal Frequency Division Multiplexing) technique. This multiplexing technique also helps solving the multipath fading by taking advantage of it and is very spectrum efficient. For several other reasons beside these, OFDM is growing its popularity day by day.

The principle behind OFDM is to divide a high data rate information bit stream into several low data rate bit stream which are transmitted over narrow orthogonal subcarriers. These subcarriers are received by the different receiving antennas and combined to produce the initial higher data rate. Therefore it allows having frequency diversity [8].

In single carrier systems with just a pair of antennas, as the data rate goes higher, the complexity at the receiver for equalization also shoots up as the bit duration becomes smaller. For OFDM getting as low data rate subcarriers are received at the receiver end, it does not enforce the high complexity of equalization. So, using multiple antennas and OFDM, multiple subcarriers which is shown in figure 1, allow much higher data rate of signal transmission [9].

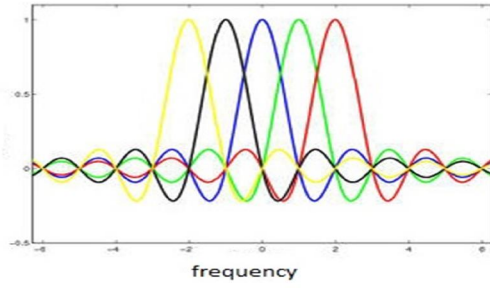


Figure 1: Different orthogonal subcarriers in OFDM signal

Let the number of subcarriers be N and the k_{th} subcarrier be $g_k(t)$ where $k=0,1..N-1$. The frequency distance for each subcarrier is Δf . Therefore symbol duration $T_s=1/\Delta f$.

The subcarrier is given by

$$g_k(t) = e^{j2\pi k \Delta f t}; t \in [-T_g, T_s] \dots \dots \dots (2)$$

After modulation of subcarriers, complex symbols $S_{n,k}$ is given by

$$S_{n,i} = 1/\sqrt{N} \sum_{k=0}^{N-1} S_{n,k} e^{j2\pi i k / N} \dots \dots \dots (3)$$

Where $i=0,1..N-1$; n is the time and k is the subcarrier.

Finally these symbols are transmitted to channel by up converting through digital to analog converter. The receiver part collects these signals and converts them back to digital. Then the guard intervals are removed and fed to FFT after converting serial to parallel streams of bits. After removing the CP, the received signals are given by

$$R_{n,k} = 1/\sqrt{N} \sum_{i=0}^{N-1} R_{n,i} e^{-j2\pi i k / N} \dots \dots \dots (4)$$

These parallel bits are again converted to serial streams of symbols and demodulated to get information bits.

As the orthogonal subcarriers are placed very close to each other oscillator clock has to be very accurate. And due to High peak to average power ration it becomes harder to implement for power limited systems [10].

We see that OFDM efficiently finds its application in the wideband (ISI) channel. In satellite systems the channels are usually narrow band due to little multipath and delay spread, high elevation angles, directional antennas and dominant LOS. But satellite mobile systems make sense for OFDM use as it experiences significant delay spread, scattering and multipath by the surrounding buildings and other terrestrial structures [11].

But when MIMO concept is combined with OFDM to enforce a spatial diversity beside frequency, it boosts the possibility of OFDM to an incredible height.

3 MIMO-OFDM MODEL FOR THE SYSTEM

3.1 MIMO – OFDM system

As mentioned earlier, MIMO-OFDM technique offers diversity in both space and frequency. Assuming the same scenario and configuration shown in figure 2, the channel impulse response from transmit antenna i and receive antenna j is

$$h_{i,j} = \sum_{l=0}^{L-1} \beta_{i,j}(l) \cdot \delta(\tau - \tau_l) \dots \dots \dots (5)$$

L is the number of independent delay paths and same power delay profile.

τ is the time delay of l_{th} path between a set of transmit and receive antennas. Time delay and variance σ^2_l are assumed same for each link. So the channel response is given by

$$H_{i,j}(f) = \sum_{l=0}^{L-1} \beta_{i,j}(l) \cdot e^{-j2\pi f \cdot \tau_l} \dots \dots \dots (6); j = \sqrt{-1}$$

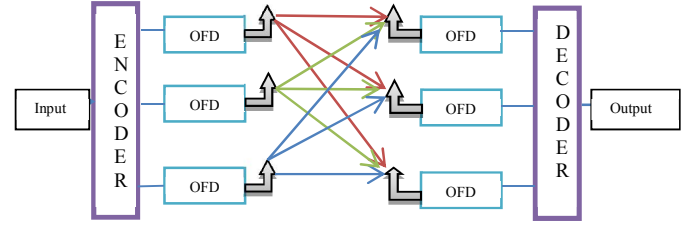


Figure 2: Summarized diagram for LTE processing.

The input bits stream after passing through channel encoder is converted into 2^b symbols where b is the number of bits per symbol. The symbols are mapped over space-frequency code and transmitted over multiple antennas. Each of these codes can be defined as

$$C = \begin{bmatrix} C_1(0) & C_2(0) & C_{M_T}(0) \\ C_1(1) & C_2(1) & C_{M_T}(1) \\ C_1(N-1) & C_2(N-1) & C_{M_T}(N-1) \end{bmatrix} \dots \dots \dots (7)$$

Where $C_i(n)$ is the symbol transmitted over n th subcarrier and $i=1,2..M_T$.

From equations 6 and 7, at the receiver, the received signal after taking the cyclic prefix off and being passed through FFT, on n th subcarrier and j_{th} receiving antenna is

$$R_j(n) = \sqrt{\frac{\gamma}{M_T}} C_i(n) \cdot H_{i,j}(n) + N_j(n) \dots \dots \dots (8)$$

3.2 MIMO Satellite Channel

Although satellite channel modeling work has not been done so far, a preliminary assumption about typical MIMO-Satellite channel is worthy. Let us consider the configuration shown below

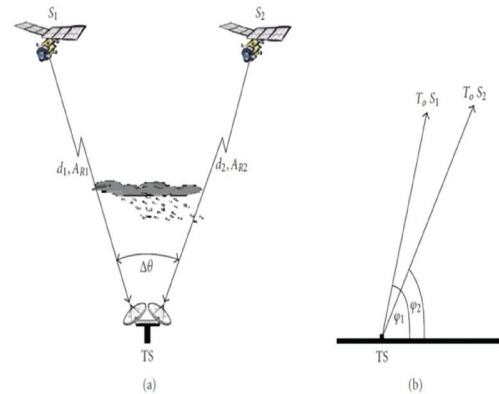


Figure 3: (a) Configuration of 2x2 MIMO satellite channel and (b) relevant elevation angles

We assume 2 satellites and 2 terminal stations configuration as shown in the figure 3(a) above. Two highly directional antennas are pointed towards two satellites s_1 and s_2 with an angle difference $\Delta\theta$. The distance between satellite and TS is d_i ($i=1,2$) and attenuation caused by the rain A_{Ri} ($i=1,2$) and θ_i ($i=1,2$) is the elevation angle. $\Delta\theta$ is taken sufficiently large that with rain fading it enables enough correlation for spatial diversity. Also we assume total loss to be $A_i = FSL_i + A_{Ri}$ ($i=1,2$). FSL is the Free Space Loss [12].

4 SIMULATION MODEL

We have simulated the model in two steps. At first, data transmission over AWGN channel and after that over Rayleigh channel and their simulated BER/SER compared to theory for checking compatibility of the developed simulated system [13].

A block diagram which is shown in figure 4 was followed for simplicity in developing the simulating codes. The diagram is given below

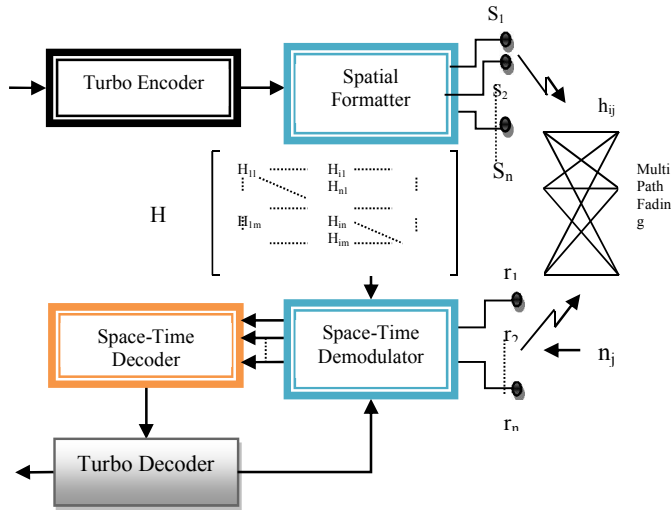


Figure 4. System Block Diagram

Turbo codes are used for simulating which are high performing FEC codes that closely approach Shannon's capacity. This code is useful to achieve reliable information transfer over bandwidth and latency constraint communication link. And this is why it is extensively used in both communication such as HSPA, Wi-MAX and Space Missions [14].

General model for simulation [15]:

- i. Generation of random bits
- ii. Modulating the bits into symbols +1's and -1's or 00,01,11,10
- iii. Adding Additive White Gaussian Noise to the signals or Pass through Rayleigh Channel when required.
- iv. Demodulation of the received symbol based on the location in the constellation
- v. Finding the difference between Transmitted bits and received bits
- vi. BER found by dividing the number of errors to bits that was transmitted.
- vii. Recap the same for other E_b/N_0 values BER graphs are plotted.

5 RESULTS AND ANALYSIS

5.1 Experimental Analysis

In this section we have described the outcome which has been simulated using MatLab.

The following figure 5 shows the BER against E_b/N_0 of BPSK and QPSK in AWGN channel. It shows the simulated BER is very close to theory over the channel. Parameters those have been used for simulations are- number of bits = 600, modulation = QPSK, bandwidth = 5MHz, FFT size = 512,

cyclic prefix = 128, turbo coding, code rate = 1/3, channel = AWGN.

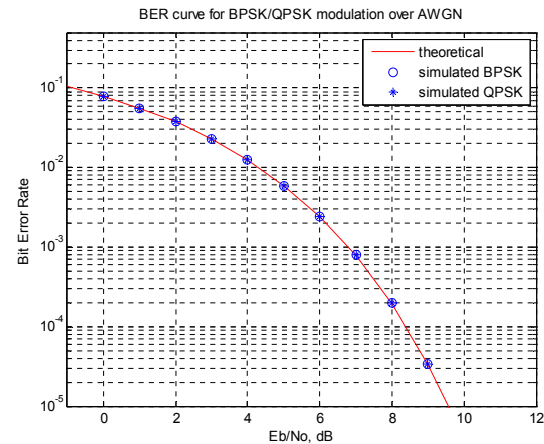


Figure 5: BER performance analysis for BPSK/QPSK over AWGN channels

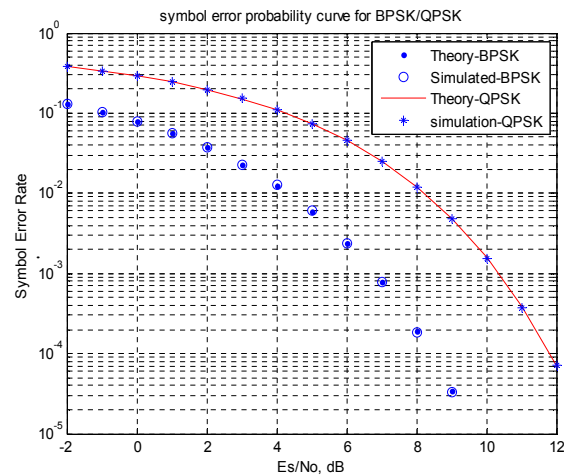


Figure 6: SER analysis for BPSK/QPSK

The above figure 6 shows the comparison for BPSK/QPSK SER over AWGN channel. We see that in order to maintain same SER as BPSK, QPSK requires higher E_b/N_0 . The reason is that it transmits two bits per symbols. Therefore per symbol it requires double the symbol energy of BPSK.

On the other hand, figure 7 highlights over Rayleigh channel. In the figure, the simulated BER is almost similar to theory. But it requires higher E_b/N_0 compared to AWGN channel.

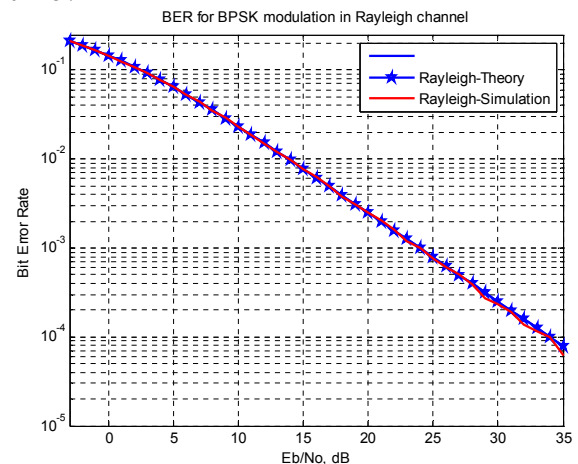


Figure 7: BER performance analysis for BPSK in Rayleigh channel

5.2 Evaluation

The main goal for this research work was to investigate the suitability of LTE over satellite systems using dual-satellite MIMO systems. Therefore satellite links were modeled as MIMO transmission model:

- The satellite channels were assumed to be identically independent fading channels.
- As per Alamouti coding the receiver had perfect channel state knowledge.
- In LTE, OFDM splits a wide band into smaller narrowband signals.

The summarized results are:

- The MIMO integrated with LTE and Satellite fading channels and behavior studied.
- We have successfully verified the implementation of MIMO-OFDM model over satellite in forward link to enhance the capacity and provide a suitable means for LTE transmission over satellite channel.

6 CONCLUSION

This research concentrated on developing a simulator for QPSK and OFDM system with turbo coding. The scenarios assumed are 2x2 MIMO with AWGN, Rayleigh and Rician channels. The basic modulation schemes used are BPSK and QPSK. Turbo coding has been used for encoding and decoding. LTE pre-coding has been used for designing MIMO pre-coder. For OFDM parameters, LTE specification with 5MHz bandwidth has been used. Finally the models designed are integrated and implemented on satellite fading channels. The results were plotted in terms of Bit Error Rate (BER) against Signal to Noise Ratio (SNR) and the plots were discussed.

LTE implementation over satellite has a great potential. For simplicity here in this project LTE transmission over 2x2 MIMO using just 5 MHz and basic modulation scheme QPSK has been examined.

7 FUTURE WORK AND DIRECTION

This project concentrated particularly on single code word for code word to layer mapping as rank 1 transmission for simplicity. In future we can check out rank 2 transmissions with two code words for code word to layer mapping on two antennas. Consequently the pre-coding scheme from LTE code book to follow will differ from the one followed in this dissertation. Hence, we may have to use composite pre-coder for better performance by adding a Cyclic Delay Diversity pre-coder on top of the existing pre-coding.

In future, LTE over satellite in uplink can also be investigated. Since LTE does not support MIMO in uplink, SIMO can be a perfect and ideal choice for mobile and cellular data transmission and thereby a good opportunity to have a look at for investigation. For modulation and multiplexing, obviously Single Carrier OFDM or Hybrid Single Carrier OFDM as mentioned in LTE standard can be used which would help further in satellite communication, keeping in mind about large satellite back-off required and also because in this case we are using GEO satellites.

ACKNOWLEDGMENT

Authors would like to give thanks Prof Barry G Evans of University of Surrey, UK and Surrey Space Centre for their support to conduct this research. This research project is partially funded by eProfessionals.org.uk.

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