IDENTIFICATION AND CONTROL OF NON LINEAR CHAOTIC SYSTEM

Project Report

Submitted in partial fulfillment of the requirements
For the degree of

MASTER OF TECHNOLOGY

IN

INSTRUMENTATION & CONTROL ENGINEERING
(Control and Automation)

By

Snehal kumar J Panchal
(12MICC10)

Instrumentation & Control Engineering Section

Department of Electrical Engineering

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382 481

MAY 2014

IDENTIFICATION AND CONTROL OF NON LINEAR CHAOTIC SYSTEM

Project Report

Submitted in partial fulfillment of the requirements
For the degree of

MASTER OF TECHNOLOGY

In

INSTRUMENTATION & CONTROL ENGINEERING
(Control and Automation)

Under the Guidance of

Prof Sandip A Mehta

Instrumentation & Control Engineering Section

Department of Electrical Engineering

INSTITUTE OF TECHNOLGY

NIRMA UNIVERSITY

AHMEDABAD-382 481

MAY 2014

Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Instrumentation and Control Engineering at Nirma University and has not been submitted elsewhere for a degree.

ii)Due acknowledgement has been made in the text to all other material used.

Snehalkumar J Panchal

Certificate

This is to certify that the Major Project entitled **"Identification and Control of Non linear Chaotic system"** submitted by **Snehalkumar J Panchal(12MICC10)**,towards the partial fulfillment of the requirements for the degree of Master of Technology (Electrical Engineering) in Control and Automation Engineering of Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date: **Place:Ahmedabad**

Project Guide

Mr.Sandip A Mehta
(Asst.Professor,I&C)
Department of Electrical Engineering,
Institute of Technology,
Nirma University,
Ahmedabad.

Head Of Department
Department of Electrical Engineering,
Institute of Technology,
Nirma University,
Ahmedabad

Director
Institute of Technology,
Nirma University,
Ahmedabad.

Acknowledgement

I would first alike to thank my guide **Asst prof.Sandip A Mehta**,His intellectual contributions, and personal encouragements are what made my work possible. In addition to the above mentioned, I owe a lot to the institute of Technology ,nirma university faculty particularly IC department. The variety of their expertise would have been worthless without their willingness to offer support and intellectual guidance on their own time.

I thank **Dr.Dipak M Adhyaru**, Section Head, Instrumentation and Control department,Institute of Technology, Nirma University, for extending all the support.

I owe my most sincere gratitude to **Dr.P.N.Tekwani**, Head of Electrical Engineering Department and **Prof.J.B.Patel**, Coordinator M.Tech Control and Automation Engineering programme for allowing me to undertake this thesis work and for his guidelines during the review process.

I am also thankful to **Dr.K.Kotecha** Director of Institute of Technology, Nirma University for his support and constant motivation.

I would also like to thanks my friends who help me and encourage me to complete my project and thesis.Last, but not the least, no words are enough to acknowledge constant support and sacrifices of my family members because of whom I am able to complete the thesis work successfully.

Finally, I would like to thank those who have watched and helped me grow. Though not reflected in the technical content of this document, the support, encouragement,and love provided by friends and family are perhaps the greatest reason for my success.

Snehalkumar J Panchal

Abstract

In the proposed project it has been required to carry out the various simulations for the different chaotic systems and also the hardware circuit is to be carried out for the nonlinear chaotic systems. The fractional order based modeling of the chaotic system will be carried out first. In this project we are going to work on Matlab software. First we simulate all the circuits which we are going to study or refer in this project. Then it has been proposed to compare all the output of circuit and to make a decision for the nonlinear system is chaotic or not. In the next part the algorithm development and simulation study will be carried out for the identification of known nonlinear system. The hardware implementation and real time identification will be carried out for the some known nonlinear chaotic system using intelligent algorithms.after doing this we have done synchronization between two fractional order and integer order system of Chua's as well as Duffing holme by using SMC (Sliding Mode Controller).

Contents

List of Figures

Nomenclature

α: Parameter value of chua's system

β: Parameter value of chua's system

$D^q x1$: Fractional order of chua's system

$D^q x2$: Fractional order of chua's system

$\Delta f Y(t)$: Uncertainty of system

$d(t)$: Acting disturbance

$u(t)$: Control input

e_i: Synchronization error

$S(t)$: Sliding surface

K_s: Controller gain

h: Step size

Chapter 1

Introduction

In simple word we can say that system which does not satisfy or follow the superposition theorem are called the non linear systems and system which satisfy superposition theorem are called linear systems[20].In any case if system contains nonlinear equation or element they are also called nonlinear system.These are the characteristics of non linear system

Non linear systems are also useful for engineers and scientist.non linear systems are also useful for mathematician.we all know that some of real systems have naturally non linear behaviour[20].It is very easy to solve linear equations by analytically and mathematically but it is very difficult to solve non linear equations by using these methods.For linear systems we have predictable out put of our system but for non linear systems we can't predict the out put or behaviour of the system.These type of non linear system gives interesting phenomena of bifurcation and chaos.chaos behaviour of system is also found in some of non linear systems. At this point we have to say that the word chaos is not uniquely defined.

In this we use a simple electronic system to develop a scheme for chaos secure communication with two coupled Chua circuits. First, we analyze separately each oscillator to study their dynamic behavior when a parameter of control is changed, and then we investigate the synchronization effect in the coupled circuits.Bifurcations of the output voltage are constructed using a resistance as a control parameter.

Chaos is a phenomenon that occurs widely in dynamical systems. From educational point ofview this phenomenon was considered to be complex and was never given importance because there was no simple analysis available, which could help students to delve into this interesting phenomenon and get some hands on experience. In the current scenario, since the presence of chaos is being realized in many fields, it is good to have some insight into this phenomenon right from the undergraduate level.

Chapter 2

Literature Review

Chua's circuit (also known as a Chua's circuit) is a simple electronic circuit that exhibits classic chaos theory behavior. It was introduced in 1983 by Leon O. Chua, who was a visitor at Waseda University in Japan at that time.The ease of construction of the circuit has made it a ubiquitous real-world example of a chaotic system, leading some to declare it "a paradigm for chaos.

We have use system identification tool box for find mathematically to measure the input and out put of the our system[1,21]. the main use of system identification tool box is for measure the input and out put can be measured for some control system as well as for some industrial application also.for nonlinear system we can say in simple word that system does not follow superposition theorem or system which are not linear are called nonlinear systems[20]. This system is often necessary because there are so many types of nonlinear systems. system identification tool box are use for nonlinear systems which are developed by focusing on specific classes of system and can be categorised into different basic approaches which are defined by a model class neural network models nonlinear ARX Models models Hammer stein-Wiener Model

2.1 Neural networks

A typical neural network consists of a number of simple processing units interconnected to form a complex network. Layers of such units are arranged so that data is entered at the input layer and passes through either one or several intermediate layers before reaching the output layer. In supervised learning the network is trained by operating on the difference between the actual output and the desired output of the network, the prediction error, to change the connection strengths between the nodes. By iterating the weights are modified until the output error reaches an acceptable level. This process is called machine learning because the network adjusts the weights so that the output pattern is reproduced[22].There are two main problem types that can be studied using neural networks static problems, and dynamic problems. Static problems include pattern recognition, classification, and approximation. Dynamic problems involve lagged variables and are more appropriate for system identification and related applications. Neural networks have been applied extensively to system identification problems which involve nonlinear and dynamic relationships.

If we want to use ANFIS for system identification tool box first we all have to decide which elements are our input signals and which are our out put variables.here in our case we have take 10 inputs for our systems they are (y(k-1), y(k-2), y(k-3), y(k-4), u(k-1), u(k-2), u(k-3), u(k-4), u(k-5), u(k-6)), and the output to be predicted is y(k). A heuristic approach to input selection is called sequential forward search, in which each input is selected sequentially to optimize the total squared error.where 3 inputs (y(k-1), u(k-3), and u(k-4)) are selected with a training RMSE of 0.0609 and checking RMSE of 0.0604.

2.2 Nonlinear ARX Model Identification

A conventional method is to remove the means from the data and assume a linear model of the form: y(k)+a1*y(k-1)+...+am*y(k-m)=b1*u(k-d)+...+bn*u(k-d-n+1) where ai (i = 1 to m) and bj (j = 1 to n) are linear parameters to be determined by least-squares methods. This structure is called the ARX model and it is exactly specified by three integers [m, n, d]. To find an ARX model for the dryer device[23], the data set was divided into a training (k = 1 to 300) and a checking (k = 301 to 600) set. An exhaustive search was performed to find the best combination of [m, n, d], where each of the integer is allowed to changed from 1 to 10 independently. The best ARX model thus found is specified by [m, n, d] = [5, 10, 2].[23]

The ARX model is inherently linear and the most significant advantage is that we can perform model structure and parameter identification rapidly. However, if a better performance level is desired, we might want to resort to a nonlinear model. In particular, we are going to use a neuro-fuzzy modeling approach, ANFIS, to see if we can push the performance level with a fuzzy inference system. Nonlinear ARX model represents a parallel form of nonlin-

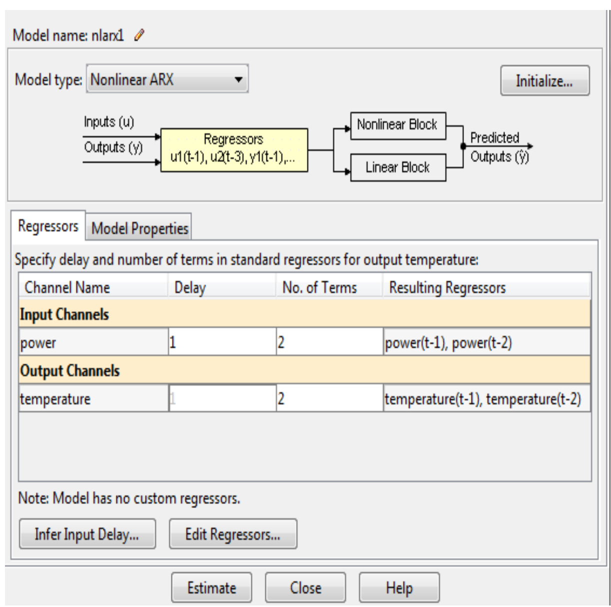


Figure 2.1: Non linear ARX model

earity where simple transformation of measured inputs and outputs (called "regressors") are used in parallel linear and nonlinear blocks to describe the observed phenomenon. Configuration of these models involves two steps setting the model regressors and configuring the properties of the nonlinearity. The two tabbed panels titled "Regressors" and "Model Properties" facilitate these two steps. For multi-output systems, these specifications have to be done separately for each output. In multi-output cases, select the output for configuration from the outputs popup (this popup is hidden if working data has only one output). The check box "apply settings to all outputs" allows specifications for regressors and model properties to be applied to all outputs.

The regressors are specified by entering the delay and number of terms in the table under the Regressors panel. Each row in the table corresponds to a single input or output channel. The first column lists the names of input/output channels. For each channel, specify the delay and number of terms in the second and the third columns respectively. The fourth column is a visual aid for the list of regressors that will be created for each channel.Press Edit Regressor. button to view a list of all regressors, select a subset for nonlinear block and create new (custom) regressors.

Nonlinearity estimator: From the Nonlinearity popup, select a type of nonlinearity to use in the nonlinear block of the model. Available choices are: Wavelet Network (default), Tree Partition, Sigmoid Network, Neural Network, Custom Network and None. Properties related to the selected nonlinearity are configured in the group box located beneath the popup. Linear Block: You may also include or exclude the linear block from the Nonlinear ARX model by using the corresponding checkbox, located adjacent to the nonlinearity popup. This choice is available only if the selected nonlinearity is one of Wavelet Network, Sigmoid Network or Custom Network. There are no configurable properties of the linear block. The only choice available, as indicated above, is whether to include it in the model or not.

Nonlinearity Configuration: When a nonlinearity type is selected in the popup, the group box beneath it updates to show the properties of the chosen nonlinearity. For most nonlinearities, the main choice is the number of units to use. Reasonable default settings are available for all properties. For more information on nonlinearity configuration.

2.3 Hammer stein-Wiener Identification

Hammer stein-Wiener model represents a series form of nonlinearity where the inputs and outputs to an Output-Error type linear model are distorted by static nonlinearities. Configuration of these models involves two steps choosing the type of nonlinearity for each channel and selecting the orders for the embedded linear model. The two tabbed panels, titled "I/O Nonlinearity" and "Linear Block", facilitate these two steps.

In the panel for I/O Nonlinearity, there is a table listing all the input and output channels and the type of static nonlinearity on each channel. The first column lists the channel names. For each channel, choose the type of nonlinearity in the second column and configure its properties in the third and fourth columns. All configurations have to be made for one row at a time.

The second column specifies the type of nonlinearity on a channel. Clicking on an entry in the second column reveals a popup menu from where the type of nonlinearity may be changed. By default, nonlinearities on all channels are set to Piecewise linear. Available choices for nonlinearities are: Sigmoid network, Saturation, Dead zone, Piecewise linear (default), Wavelet network, One-dimensional polynomial, Custom network and None. "None" indicates an absence of nonlinearity in the corresponding I/O channel. For one-dimension polynomial nonlinearity (POLY1D), the "number of units" refers to the degree of the polynomial.

In the third column of the table, specify the number of units to be used in the nonlinearity selected in the second column. For Saturation and Dead zone, the number of units is inactive (this option is not applicable). Similarly, there is no value for number of units if nonlinearity is set to None. For wavelet network, this table cell is an editable popup menu: you may either choose one of the three listed option ("Select automatically", "10", "Select interactively during estimation") or type in a positive integer in the cell. For One-dimensional Polynomial nonlinearity, enter the degree of the polynomial in this column (default: second degree).The fourth column of the table offers more options for configuring the chosen nonlinearity (i.e. the nonlinearity type listed in the second column of the same row).
Wavelet Network: If nonlinearity type is Wavelet network, this column offers an Advanced... button. Advanced properties related to the structure of the

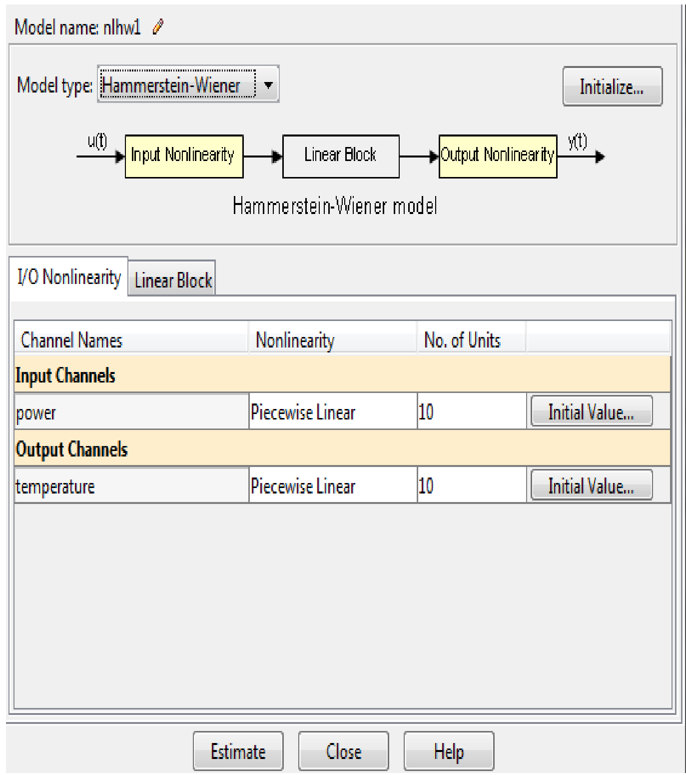


Figure 2.2: Hammer stein-Wiener model

wavelet network, such as Dilation step and Maximum number of levels, may be configured by clicking on this button. See the documentation on wavenet for information on these properties.

Saturation, Dead Zone and Piecewise Linear: The fourth column contains a button called Initial value. Press this button to (optionally) specify the initial values of the breakpoints for saturation, dead zone or piecewise linear nonlinearity. For saturation, the breakpoints denote the two ends of the linear interval. For dead zone, the breakpoints are the two end of the zero (dead) interval. For piecewise linear case, the number of breakpoints equals the number of units specified in the third column of the table.

Sigmoid Network or None: No options are offered. One-dimensional polynomial: Enter the initial values (optional) of the polynomial coefficients, as a row vector. The length of the coefficients vector is D+1, where D is the Degree of the polynomial (entered in column 3 of the I/O Nonlinearity table). Custom Network: The fourth column contains a button called "Unit function...". Press this button to specify a unit function for the custom network. Note that specification of a unit function is necessary for the custom network to be functional. Note: The option "None" for the type of nonlinearity implies absence of nonlinearity on that channel. This is equivalent to choosing "unitgain" as type of nonlinearity in the corresponding IDNLHW model object (when working in the MATLAB Command Window). For more information on this choice, see documentation on nonlinearity estimator called "unitgain".

The linear model configuration is similar to that of the corresponding linear OE model. Orders of polynomials B and F and the input delay nk need to be specified in the table titled "Model Order". These values must be entered for one output at a time. The output to configure may be changed in the popup labeled "Choose output". Click on the "Use same orders for all outputs" checkbox to use the same order values for all outputs. The first column of table lists the input channels. Orders of polynomials B and F and the input delay (nk) have to be chosen for each input channel. In second column, enter the order of numerator polynomial B, which is equal to the number of zeros+1 in the corresponding linear model. In third column, enter the order of denominator polynomial F, which is equal to the number of poles in the corresponding linear model.

A black-box tester is unaware of the internal structure of the application to be tested, while a white-box tester has access to the internal structure of the application[24]. A gray-box tester partially knows the internal structure, which includes access to the documentation of internal data structures as well as the algorithms used Gray-box testers require both high level and detailed documents describing the application, which they collect in order to define test cases Gray-box testing is beneficial because it takes the straightforward technique of black-box testing and combines it with the code targeted systems in white-box testing. Gray-box testing is based on requirement test case generation because it presets all the conditions before the program is tested by using the assertion method. A requirement specification language is used to make it easy to understand the requirements and verify its correctness[25].

Chapter 3

Concept of Chua's Circuit

In this project we have use chua's circuit.it is a very simple circuit that gives us interesting behaviour of bifurcation and chaos.For appearing of chaos behaviour in our circuit it must have to satisfy some criteria.it may contain more than two energy storage elements one nonlinear element and one locally activate register[5,6].

3.1 Classical Chua's Oscillator

For appearance of chaos in our circuit chua's circuit satisfy all criteria which are been needed for appearance of chaos and circuit gives chaotic behaviour.For classical chua's oscillator active resistor supply energy to separate trajectories and three dimensional state space equations permits circuit for chaotic behaviour.chaos produce in our circuit[2,4].

we have study chua's circuit which is an ideal circuit.the circuit consist of two capacitors inductor resistor R and chua's diode(NR).by applying KCL in circuit it can be describe by following three equations.

$$\frac{dV_1(t)}{dt} = \frac{1}{C_1}[G(V_2(t) - V_1(t) - f(V_1(t))]$$

$$\frac{dV_2(t)}{dt} = \frac{1}{C_2}[G(V_1(t) - V_2(t) - I_L(t)]$$

$$\frac{dI_L(t)}{dt} = \frac{1}{L}[-V_2(t) - R_L I_L(t)]$$

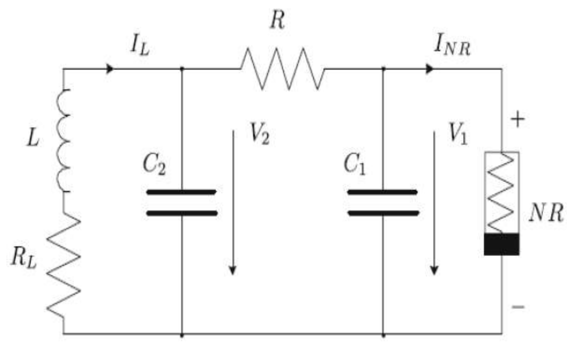
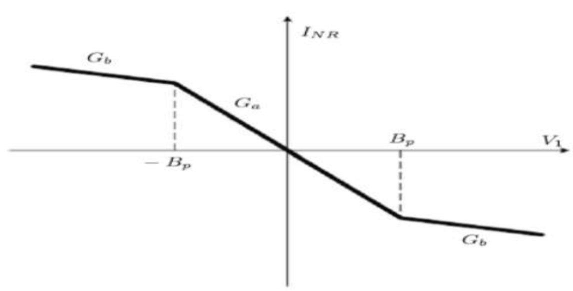


Figure 3.1: Simple chua's circuit

In above three equations G is known as conductance.current pass through the inductor is assign as IL(t).voltages over capacitors are V1(t) and V2(t).Piecewise-linear v-i characteristic of chua's circuit is assign as (V1(t)) and NR is known as chua's diode.Below figure shows the piece wise linear characteristic of chua's system.

$$I_{NR}(t) = f(V_1(t)) = G_b V_1(t) + \frac{1}{2}(G_a - G_b)(|V_1(t) + B_p| - |V_1(t) - B_p|)$$



$$x(t) = \alpha(y(t) - x(t) - f(x))$$
$$y(t) = x(t) - y(t) + z(t)$$
$$z(t) = -\beta y(t) - yz(t)$$

3.2 Classical Chua's simulation result

In simulation we have take three values for find out a chaotic system In the first case we have take same order of the system In the second case we have take different order of the system In the third case we have take two order of the system same and third order is different Order of system=q1,q2,q3.

Classical Chua's simulation result for same order of system

In the first case we have take same order of the system means we have take same value of q1=q2=q3=0.99.

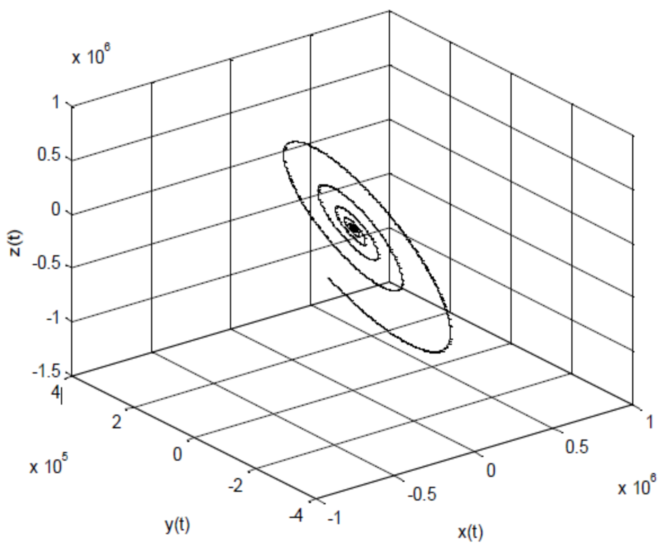


Figure 3.2: Simulation result of chua's system for q1=0.99 q2=0.99 q3=0.99

In above figure we can see the chaotic behaviour of the circuit.strange attractor is not produce in the above figure but still the system is chaotic.in this case we have taken parameters a=10.7,b=10.5,c=0.27.tottal order of system q=0.99,simulation time T=100s,and initial conditions are x(0)=0.6,y(0)=0.1,z(0)=-0.6[7].

We know that chaotic system or non linear system highly depend on the initial condition of a system.in first case we take order of the system same.we can see from figure that system is chaotic and it is oscillating from one point to another point.

3.3 Classical Chua's simulation result where two order of system are same third order is different

In the second In the second case we have take two order of the system same and third order is different q1=q2=0.99,q3=0.92 In above figure we can see

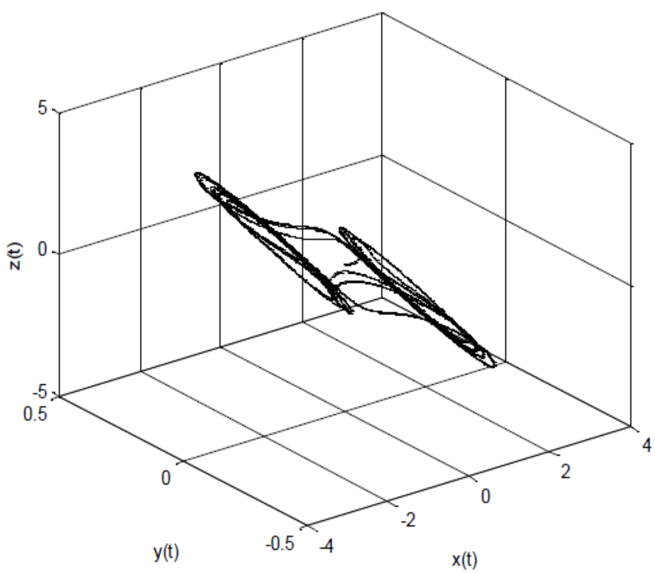


Figure 3.3: Simulation result of chua's system for q1=0.99 q2=0.99 q3=0.92

that two order of systems are same third order is different.so in this case total order of system q=0.97.strange attractor are produce in this system for that parameters value are a=10.7,b=10.5,c=0.27.simulation time T=100s,and initial conditions are x(0)=0.6,y(0)=0.1,z(0)=-0.6[7].

3.4 Classical Chua's simulation result where all three order of system are different

In the third case we have take three different order of the system.q1=0.99,q2=0.92,q3=0.93

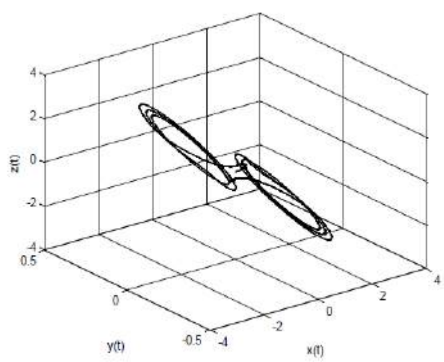


Figure 3.4: Simulation result of chua's system for q1=0.99 q2=0.92 q3=0.93

In above figure we can see that all three order of systems are different.so in this case total order of system q=0.95.strange attractor are produce in this system for that parameters value are a=10.7,b=10.5,c=0.27.simulation time T=100s,and initial conditions are x(0)=0.6,y(0)=0.1,z(0)=-0.6[7].

3.5 Using Chaotic System Train Neural network anfis data

In this we have take input and output data from chua's circuit.then we have call that values in neural network which trains data and gives us the input and output graph of our system.also give us the error graph of our chua's circuit After getting a input and out put graph we get the error graph for our train data from figure we can see that after some time error is reducing which means that circuit give us the best result for chaotic system[12].

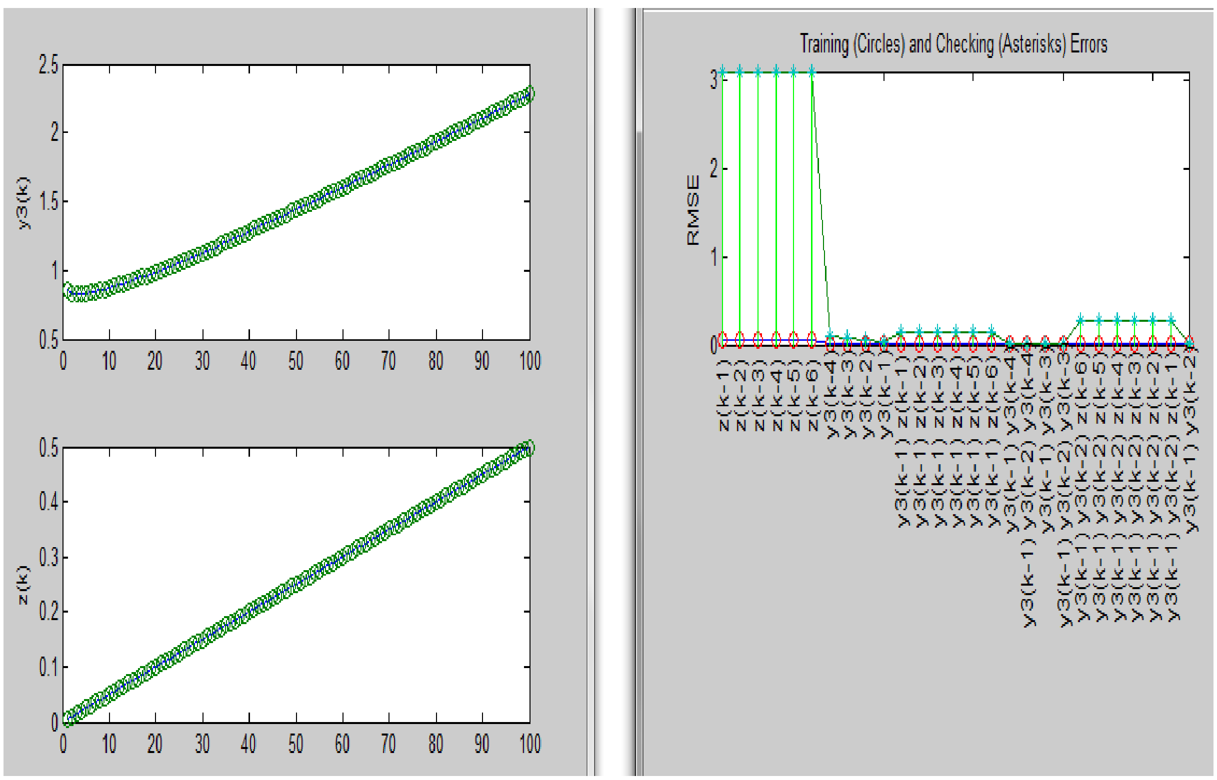


Figure 3.5: InputZ(K)ouputY3(K) Error graph

Chapter 4

Concept of Volta's Circuit

The system was discovered by Volta in 1984.Volta's system is described by the system of state differential equations

$$\frac{dx_(t)}{dt} = -x(t) - ay(t) - z(t)y(t) \tag{4.1}$$

$$\frac{dy_(t)}{dt} = -y(t) - bx(t) - x(t)z(t) \tag{4.2}$$

$$\frac{dz_(t)}{dt} = cz(t) + x(t)y(t) + 1 \tag{4.3}$$

4.1 Volta's simulation result

In simulation we have take three values for find out a chaotic system In the first case we have take same order of the system In the second case we have take different order of the system In the third case we have take two order of the system same and third order is different Order of system order is defined by=q1,q2,q3[5,12].

4.2 Volta's simulation result for same order of system

In the first case we have take same order of the system means we have take same value of q1=q2=q3=0.99 In first case all three order of system are

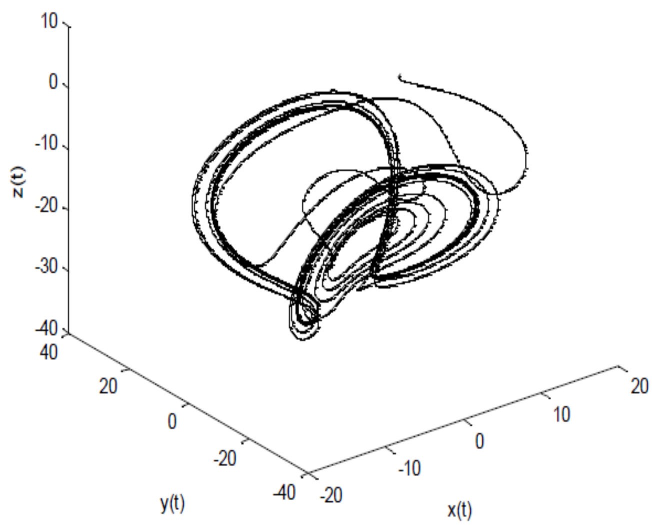


Figure 4.1: Simulation result of Volta's system for q1=0.99 q2=0.99 q3=0.99

same.chaotic behaviour of system is projected into 3D state space.for this total order of system q=0.99.for this the parameters values are a=19,b=11,c=0.7 and simulation time is T=100 second.Initial conditions are x(0)=8,y(0)=2,z(0)=1

4.3 Volta's simulation result where two order of system are same third order is different

In the second case we have take two order of the system same and third order is different q1=q2=0.99,q3=0.92 chaotic behaviour of system is projected into 3D state space.for this total order of system q=0.97.for this the parameters values are a=19,b=11,c=0.7 and simulation time is T=100 second.Initial conditions are x(0)=8,y(0)=2,z(0)=1

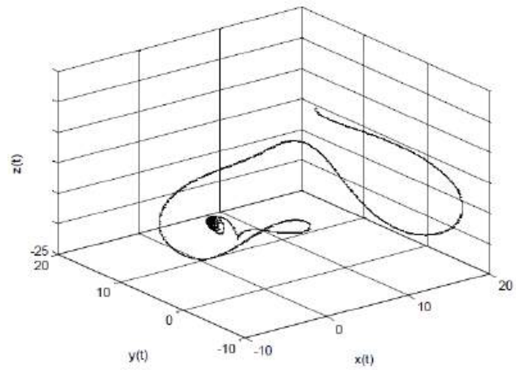


Figure 4.2: Simulation result of Volta's system for q1=0.99 q2=0.99 q3=0.92

4.4 Volta's simulation result where all three order of system are different

In the third case we have take three different order of the system.q1=0.99,q2=0.92,q3=0.93 In Fig is shown the chaotic behavior for fractional-order chaotic system.chaotic

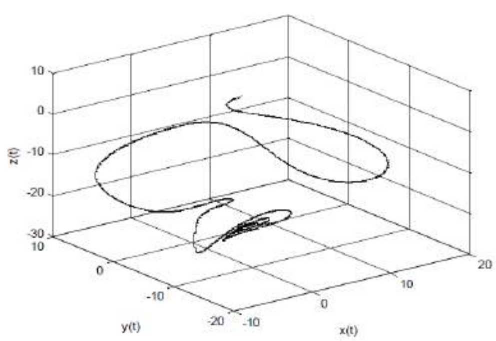


Figure 4.3: Simulation result of Volta's system for q1=0.99 q2=0.92 q3=0.93

behaviour of system is projected into 3D state space.for this total order of system q=0.97.for this the parameters values are a=19,b=11,c=0.7 and simulation time is T=100 second.Initial conditions are x(0)=8,y(0)=2,z(0)=1 time step h =0.1.As we can see,behavior of the fractional-order Voltas system is still chaotic because we have observed double-scroll attractor

4.5 Using Chaotic System Train Neural network anfis data

In this we have take input and output data from volta's circuit.then we have call that values in neural network which trains data and gives us the input and output graph of our system.also give us the error graph of our volta's circuit from figure we can see that after sometime error is reduce which means circuit gives the best result for chaotic system.

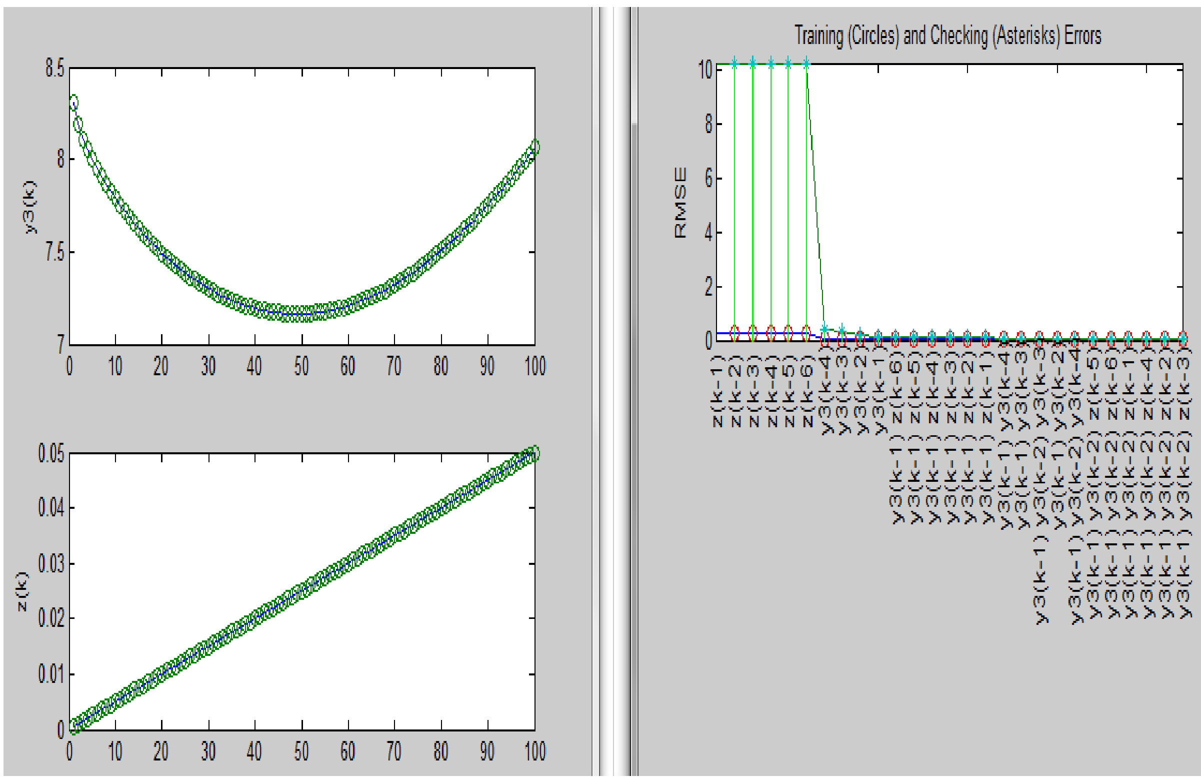


Figure 4.4: InputZ(K)ouputY3(K) Error graph

Chapter 5

Simulink and System Identification Tool Box

5.1 Simulink

In simulink we have make a simple nonlinear block for a system which consist of ramp input coulomb and viscous friction block.from that we take input and out in to work space.from workspace we import data in system identification tool box

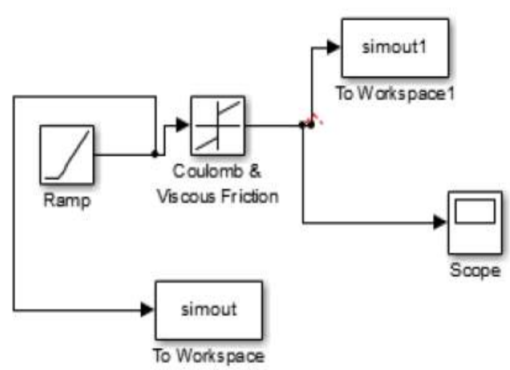


Figure 5.1: Simple nonlinear block

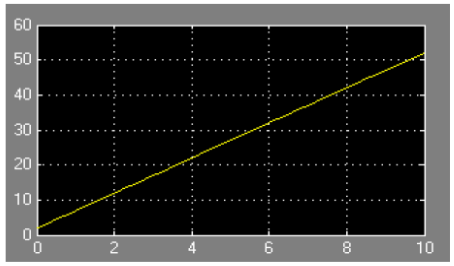


Figure 5.2: Simulink output

5.2 System identification tool box

system identification is a tool box where we find out different techniques for time domain data,frequency domain data,etc.in this tool box we import our data from workspace in time domain form.then with help of nonlinear ARX method we get time domain output nLRx out put and system best fit out put

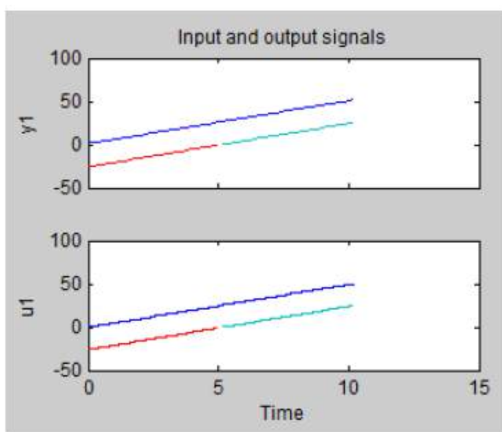


Figure 5.3: Time plot u1 v1

Chapter 6

Hardware Description Of Chua's Circuit

6.1 Circuit design

There are many variations on how to build Chua's circuit, but this is the basic design.there is not much to it. This is the standard Chua's circuit used in research and a number of experiments, but there are many different ways to realize the full circuit. Chua's circuit is literally the simplest chaotic circuit. However, when building this circuit at home be aware that, as a chaotic circuit, very slight variations can cause large effects or failure of the entire circuit. A loose connection or uneven voltages will dramatically affect the output. Building Chua's circuit on a breadboard can be a frustrating endeavor if care is not taken. Even a slight bump can loosen connections enough to wildly change the output. But that can be fun too! Also, the quality of the output from a breadboard will be quite less than that of a soldered circuit board[27]. The Chua's diode must be constructed as no one manufactures them. There are a number of ways to create a Chua's diode, which is actually a type of nonlinear resistor. In you can see Chua's diode made from only resistors and op-amps. Figure C is a little different and employs standard diodes. Both designs equally satisfy the circuit, but Figure B is easier to make.The inductor can also be replaced and accurately simulated with an additional circuit called a gyrator, as shown in out of the same components. To understand how this simulation is accomplished, please read this PDF on the Antoniou Inductance-Simulation Circuit[27]. Thus, with

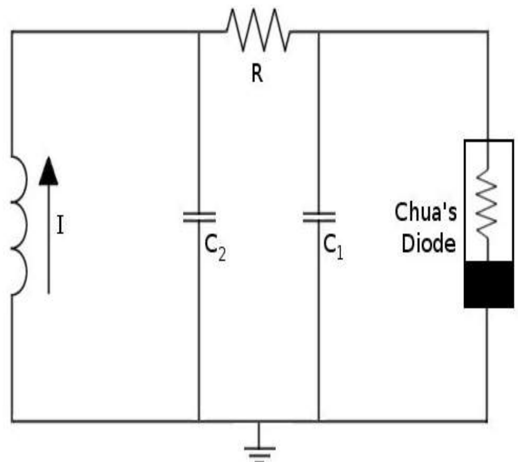


Figure 6.1: Basic chua's circuit

this inductor simulator, a fully realized circuit can be built from only resistors, capacitors and op-amps.These circuit components can be found lying around in most labs and are readily available off the shelf in any RadioShack or similiar establishment[27].

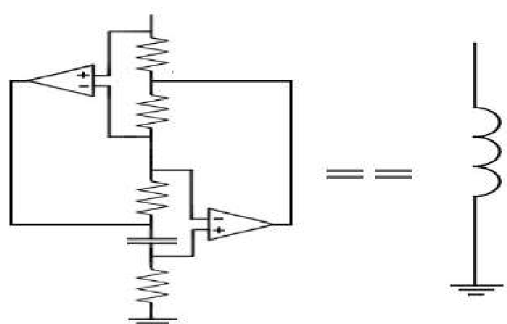


Figure 6.2: Gyrator simulating inductor

6.2 Components

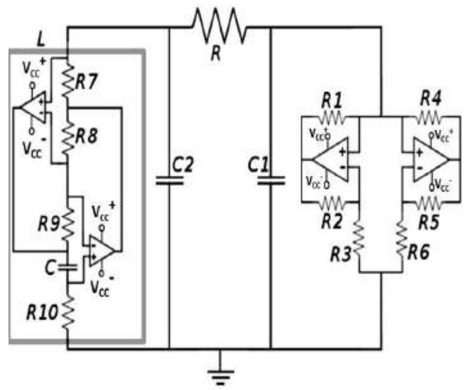


Figure 6.3: Fully labeled chua's circuit

R=2.5 k (pot.)C=100nF R1=220 C1=10 nF R2=220 C2=100 nF R3=2.2k R4=22.0 k L=15 mH R5=22.0 k R6=3.3 k R7=100 R8=1.0 k R9=1.0 k R10=2.5 k (pot.)

While there are many ways to build a standard Chua's circuit and many variations on the standard, for simplicity, we will focus here on the version made only from resistors, capacitors and op-amps as shown on the previous page.There are many factors to consider when selecting components, e.g. circuit size, accuracy needed, cost etc. I'll show you how an effective, cheap and compact circuit can easily be built with 9-volt power supply and the aforementioned components. All op-amps used are TL082. Each chip has two op-amps–one on either side. You could also use the TL084, which has 4 op-amps, depending on your specific circuit design. L here represents the inductance value of the gyrator, which we are using in place of an actual inductor. Calculating this value can be done as follows:

$$L=(R7R9R10C)/R8$$

This gyrator simulates an ideal inductor, and you will see later how this is useful for measuring the signals produced. If you don't wish to use a gyrator, please read our page on using real physical inductors.For capacitors, I highly recommend you avoid the common, round, ceramic capacitors. Go for mylar capacitors. They work much better and it will make the output much sharper.Precision resistors are not really worth it unless you want really clear and precise double scrolls. Regular resistors work just fine. But you do want to get nice, easy to adjust potentiometers. You will be spending most of your time turning these little dials trying to get the right patterns to show up, and you will thank yourself for not using the screwdriver-adjustable only pots. Get something with big nobs that are easy to tune and have fine control. These circuits are sensitive and you want to have control over what is going on[27].

6.3 Hardware setup and double scroll attractor

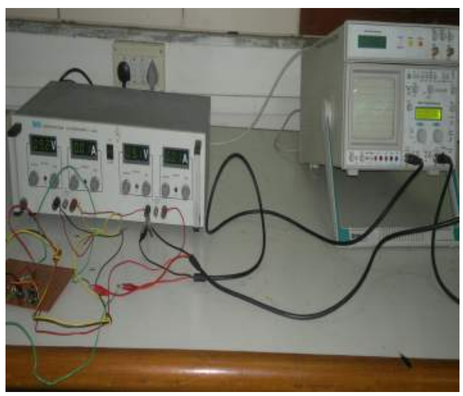


Figure 6.4: Hardware setup

In Figure we can see Chua's circuit.which is soldered on a grid-style circuit board,where power supply of 9 volt connected to negative and positive terminal of circuit.we have take two out from capacitor c1,c2.which are goes in analog oscilloscope.we can see from figure There are 3 signals that you will want to measure on the Chua's circuit: X, Y, and Z. X is the voltage across the capacitor C1, Y is the voltage across the capacitor C2, and Z is the current through the inductor. Since we are using a gyrator to simulate the inductor, all we need to do is measure the voltage at point P since we can determine the state vectors from just that. The actual current through our simulated inductor can be calculated by[27].

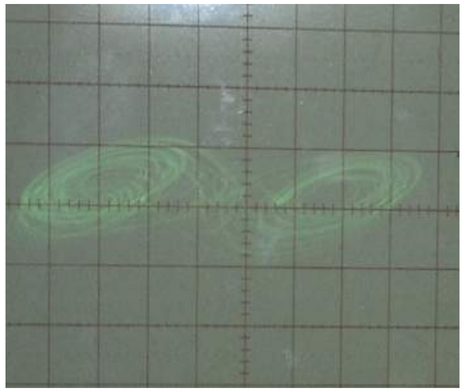


Figure 6.5: Double scroll attractor

Z=(VP-Y)/R7

Eventually you should come up with something like. This is the classic chaotic double-scroll attractor also known as Chua's attractor. This figure, however, comes from an analog scopenot a digital one.You can try plotting the circuits with X vs Y, X vs Z and Y vs Z to see the scroll from different 2D perspectives. In a simulation you can actually rotate the attractor in 3D. Check out our simulation page to see the double scroll evolve much slower than you will be able to see on an oscilloscope. It will give you a feel for how the signals interact to actually create the double scroll attractor The

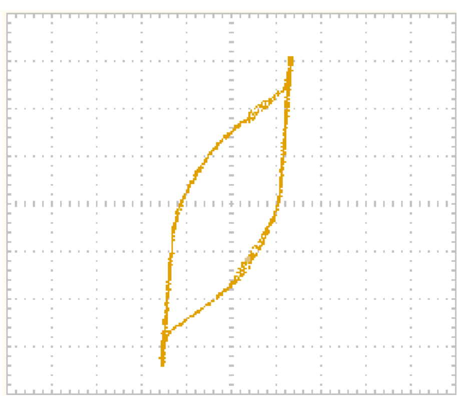


Figure 6.6: Lemon attractor

best advice can give you when you are struggling to find the double scroll, wildly tuning both pots with no luck, is to very slowly tune one at a time until you see a shape like in Once you see this lemon shape, start tuning the other potentiometer, slowly again, until you get the double scroll.

Figure 6.7: Saturated double scroll attractor

Another problem you may have is a saturated scroll where the scroll seems to be bounded on two sides and is flat instead of rounded. Saturation, or 'voltage clipping', is caused by voltage that exceeds the ideal functional range of the component and reaches the limits of the components of the circuit. 'By definition, the Double Scroll attractor is bounded. This is important because all physical resistors are eventually passive, meaning simply that for a large enough voltage across its terminals, the power consumed by a real resistor is positive[27].

Chapter 7

Duffing Holme Chaotic System

7.1 Introduction

Duffings Holme system was introduced in 1918 by G. Duffing, with negative linear stiffness,damping and periodic excitation is often written in the form.To get the fractional-order Duffings system, Equation can be rewritten as a system of the first-order autonomous differential equations in the form[8,9].

$$D.^{q}x1 = x2 \tag{7.1}$$

$$D.^{q}x2 = x1 - \alpha x2 - x1.^{3} + \beta cos\left(t\right) \tag{7.2}$$

Parameters alpha=0.25 and beta=0.3 respectively. When order of system is reduced the chaos and behaviour of system is oscillatory and gives chaotic behaviour.In slave system we have add disturbance and uncertainty in system

7.1.1 Duffing Holmes simulation result

In simulation we have take different order of the system than we have done different simulation with help of fde 12 method and differential equation of our system.

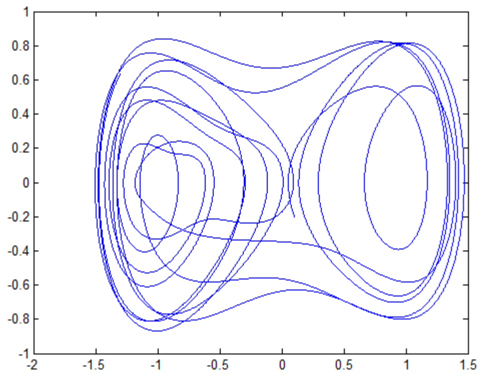


Figure 7.1: Duffing Holmes simulation result for q=1

In above fig we can see chaotic behaviour of duffing homle's system.Strange attractor is produce in our system for parameters α=0.25,β=0.3.for this initial conditions x(0)=0.2,y(0)=-0.2 simulation time t=100s and step size h=0.005

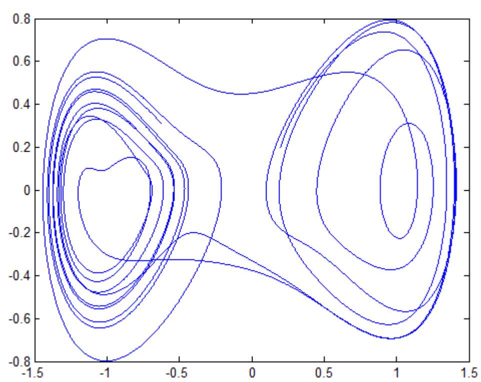


Figure 7.2: Duffing Holmes simulation result q=0.98

In second case we have change value of q and run the differential equation in matlab with help of fde12 method which is use for derive fractional order differential equations Strange attractor is produce in our system for parameters α=0.25,β=0.3.for this initial conditions x(0)=0.2,y(0)=-0.2 simulation time t=100s and step size h=0.005[8,9].

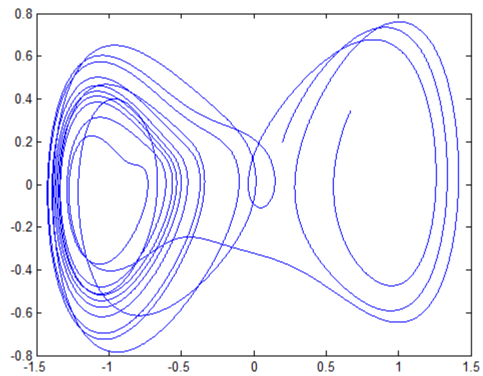


Figure 7.3: Duffing Holmes simulation result q=0.97

In third case we have change value of q and run the differential equation in matlab with help of fde12 method which is use for derive fractional order differential equations.Phase trajectory (attractor) in plane xy for the integer-order Duffings system with parameters = 0.25, = 0.3, = 1, and initial conditions (x(0),y(0)) = (0.2,0.3).In above Fig is depicted the limit cycle of the fractional-order Duffings system.

Chapter 8

SMC and Synchronization For Chaotic System

Synchronization means One system drive the another system means by changing the value in first system there is been sudden change in other system are called synchronization.in synchronization one system is work as master and other system is work as slave.we can control the other system by master.so it is also called master slave system. synchronization and control of system are almost same.It has been very difficult to synchronize two chaotic systems. for stability analysis of chaotic system it is very difficult to implement Lyapunov method for analysis[8,9].

For modeling a new physical system we have to provide new mathematical structure for designing control system.Fractional order could attract scientist and researcher for control task in two different ways.In first case it gives an interesting idea for designing a controller in different way.This is due to the fact that, in most cases, controller design procedure is heuristic.fractional order will provide a good mathematical structure in which many characteristics of system behaviours are simply related to less number of parameters.According to this the paradigm of design should be changed. The second reason of attraction is related to the performance analysis of the designed system.fractional order should provide a mathematical structure in which stability analysis is done in many cases .

In this synchronization and controlling method we have use Sliding Mode Controller (SMC)controller for controlling the synchronization and its behaviour after adding disturbance and uncertainty.when SMC is introduce in the system.system works or behave as a robust system.so after introduced

SMC or control law in the system disturbance and uncertainty did not affect the behaviour of the duffing holme's system.system become stable after some time.It is also depend on the parameter value and disturbance which we have taken in the system.This makes the fractional calculus easier to find an appropriate function for stability analysis.This idea is verified when SMC is used to synchronize fractional order Duffing Holmes chaotic system[13,14].

8.1 Simulation with out adding control law and synchronization

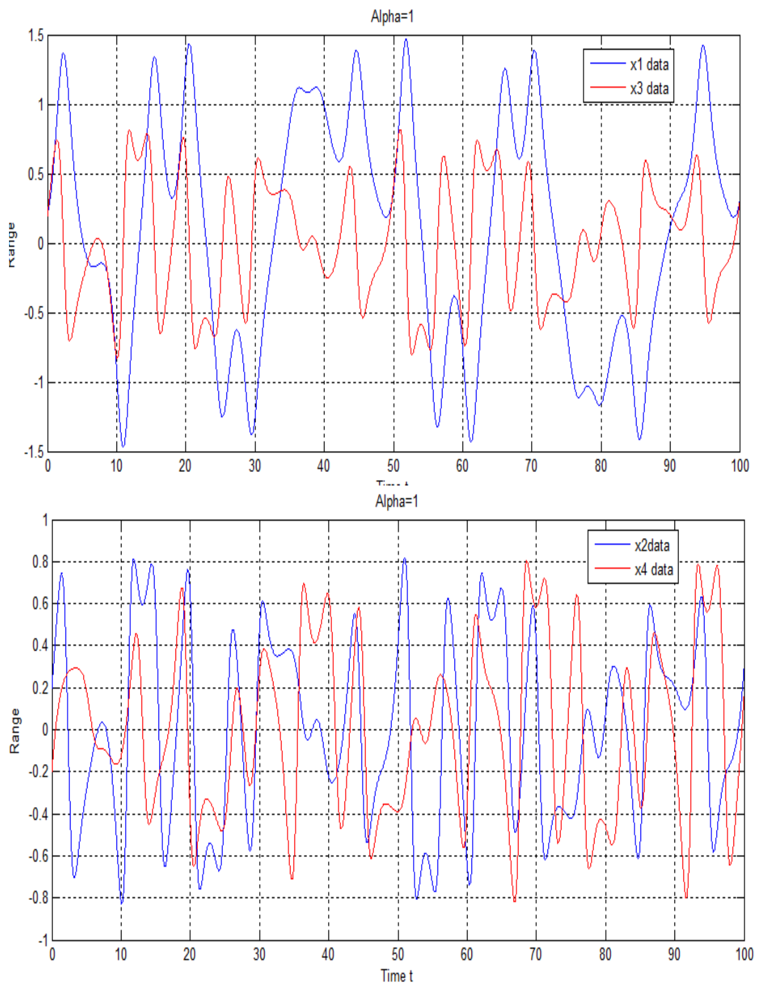


Figure 8.1: With out control law graph for q=1

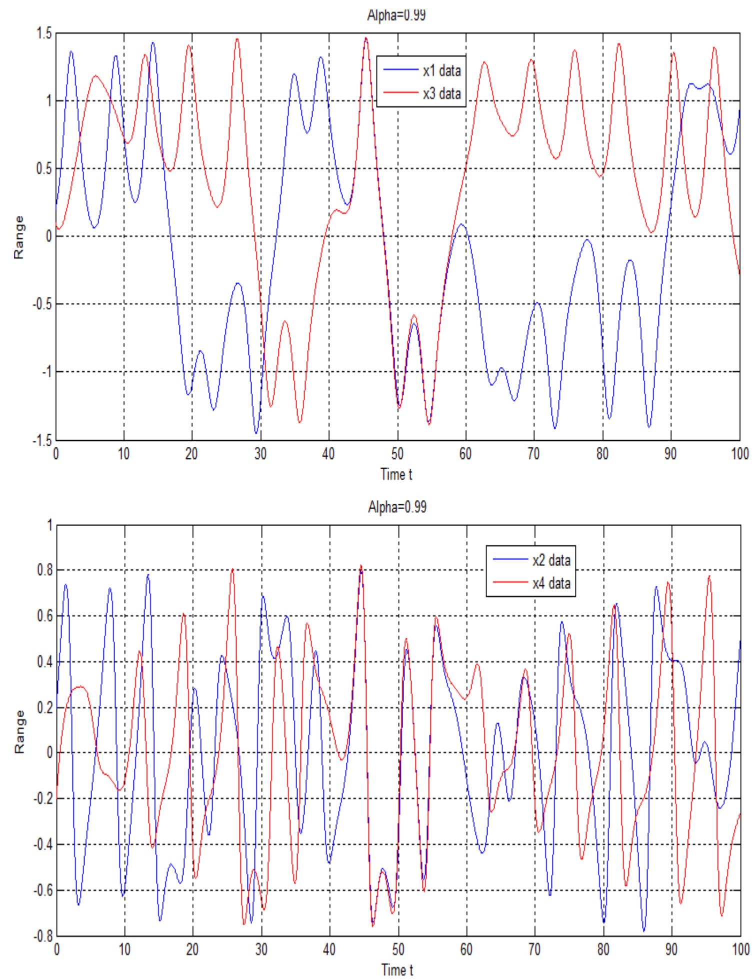


Figure 8.2: With out control law graph for q=0.99

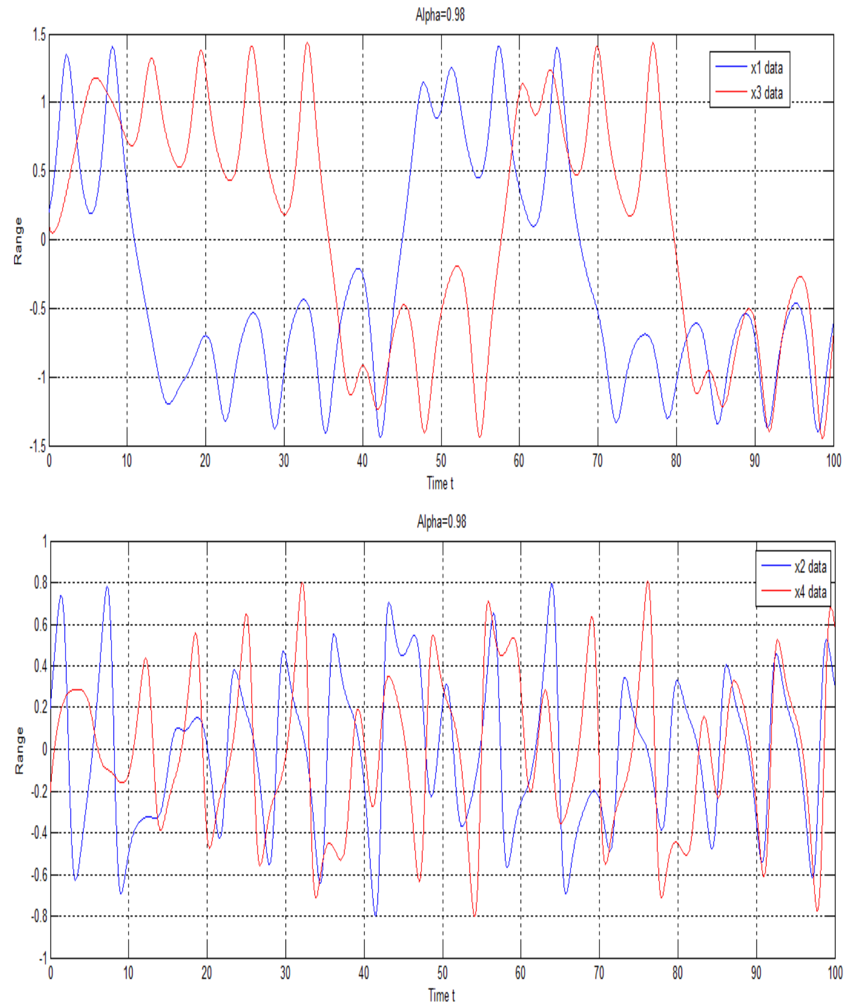


Figure 8.3: With out control law graph for q=0.98

8.2 Sliding mode synchronization of fractional order systems

In synchronization of system one system will work as master and another different system work as slave.we have to control our system so we have to design a controller in that manner a nonlinear system obtains signal from system which is known as master to tune the other system which works as slave.we have use master and slave with fractional order differential equations[8].

$$D.^q x1 = x2 \tag{8.1}$$

$$D^q x2 = f(X, t) \tag{8.2}$$

$$D.^q y1 = y2 \tag{8.3}$$

$$D^q y2 = f(Y, t) + \Delta f(Y, t) + d(t) + u(t) \tag{8.4}$$

for providing control input u(t) a sliding mode control is introduce 1- Constructing a sliding surface which represents a desired system dynamics. 2- Developing a switching control law to make the sliding mode possible on every point in the sliding surface. Any states outside the surface are driven to reach the surface in a finite time. However, to achieve the control law, u(t), the synchronization error is defined as:

$$e = x - y \tag{8.5}$$

we can design sliding surface by following equation

$$S(t) = c1e1 + c2e2 \tag{8.6}$$

we have to select c1 and c2 in such easy way that the sliding surface of the system vanished quickly.when states of the sytem are reach to their desire point or surface they become robust there will be no change in its behaviour.when this kind of effect occurred called in the system we can say that SMC has taken place. After this effect the whole system is controlled by Sliding mode control(SMC).we have to chose c1 and c2 in that way when they reach to surface they behaves like desired point[19]. The sliding mode control(SMC) will be deigned in two phases: 1. The reaching phase when S(t)is not equal 0 and 2. The sliding phase by S(t)=0. A sufficient condition for the error to move from the first phase to the second one, is as follows:

$$S(t)\dot{S}(t) \leq 0 \tag{8.7}$$

above condition is called the sliding condition.when disturbance and uncertainty are absent the force on main equation is obtain by S(t)=0.the equation is derived into fractional order equation.

first we have studied integer order now we are going to study fractional order duffing system by following equations:

$$D.^{q}x1 = x2 \tag{8.8}$$

$$D^{q}x2 = x1 - \alpha x2 - x1^{3} + \beta cos(t) \tag{8.9}$$

$$D.^{q}y1 = y2 \tag{8.10}$$

$$D^{q}y2 = y1 - \alpha y2 - y1^{3} + \beta cos(t) + \Delta f(Y,t) + d(t) + u(t) \tag{8.11}$$

where

$$Deltaf(Y,t) = 0.1sin(t)\sqrt{y1^{2} + y2^{2}}andd(t) = 0.1sin(t) \tag{8.12}$$

results the control law, which is as follows

$$u(t) = (c1/c2)e2+e1-\alpha x2-x1^{3}+\alpha y2+y1^{3}-0.1sin(t)\sqrt{y1^{2} + y2^{2} + 1}+K_{s}sat(S(t) \tag{8.13}$$

simulation result of duffing holme's systems are shown in figure.we have choose parameter value like c1 and c2 are same.gain k=10.The control signal sliding surface and synchronization of states X and Y for q = 0:98 are also shown in Fig. Similarly, the results for different values of q = 0:96 and q q 0:9.7 are shown in Fig, respectively. It should be noted that the control is activated at t = 20 s.by changes the value of q we can get faster response of master as well as from slave system.synchroniztion process also done faster by using SMC and changing q[15,16].

8.3 Simulation result and synchronization of Duffing Holmes system

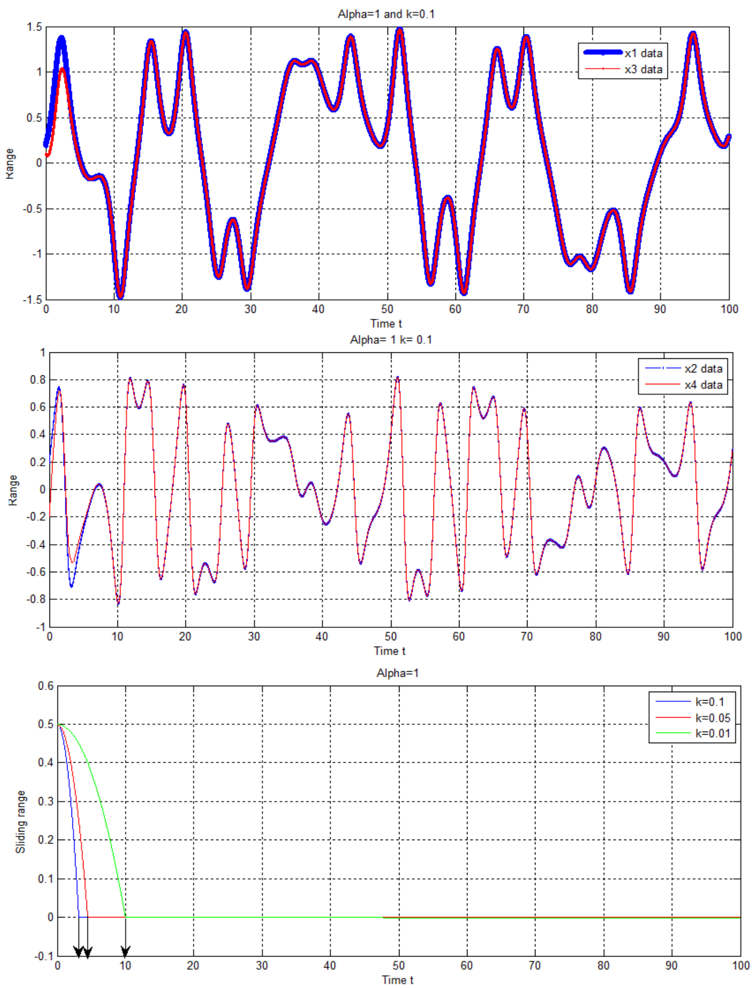


Figure 8.4: Synchronize graph e1 for q=1

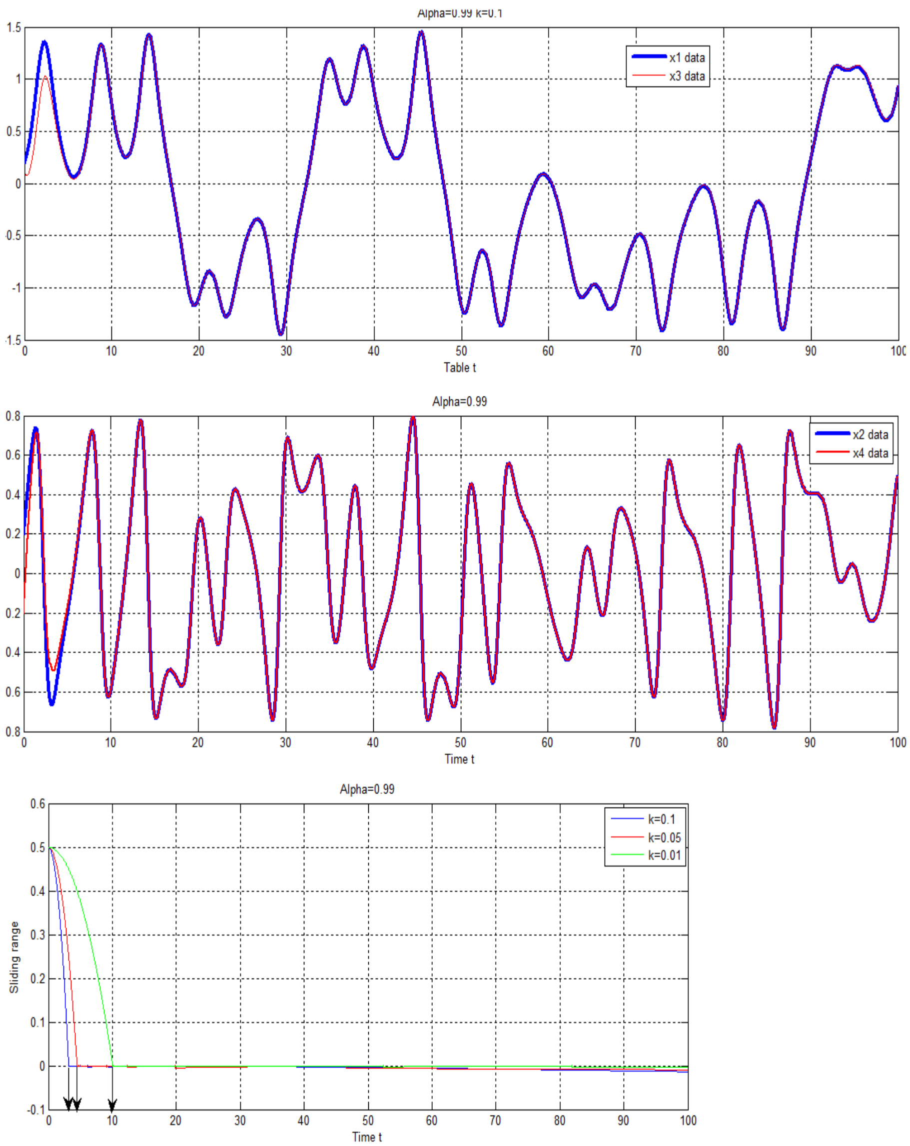


Figure 8.5: Synchronize and sliding graph q=0.99

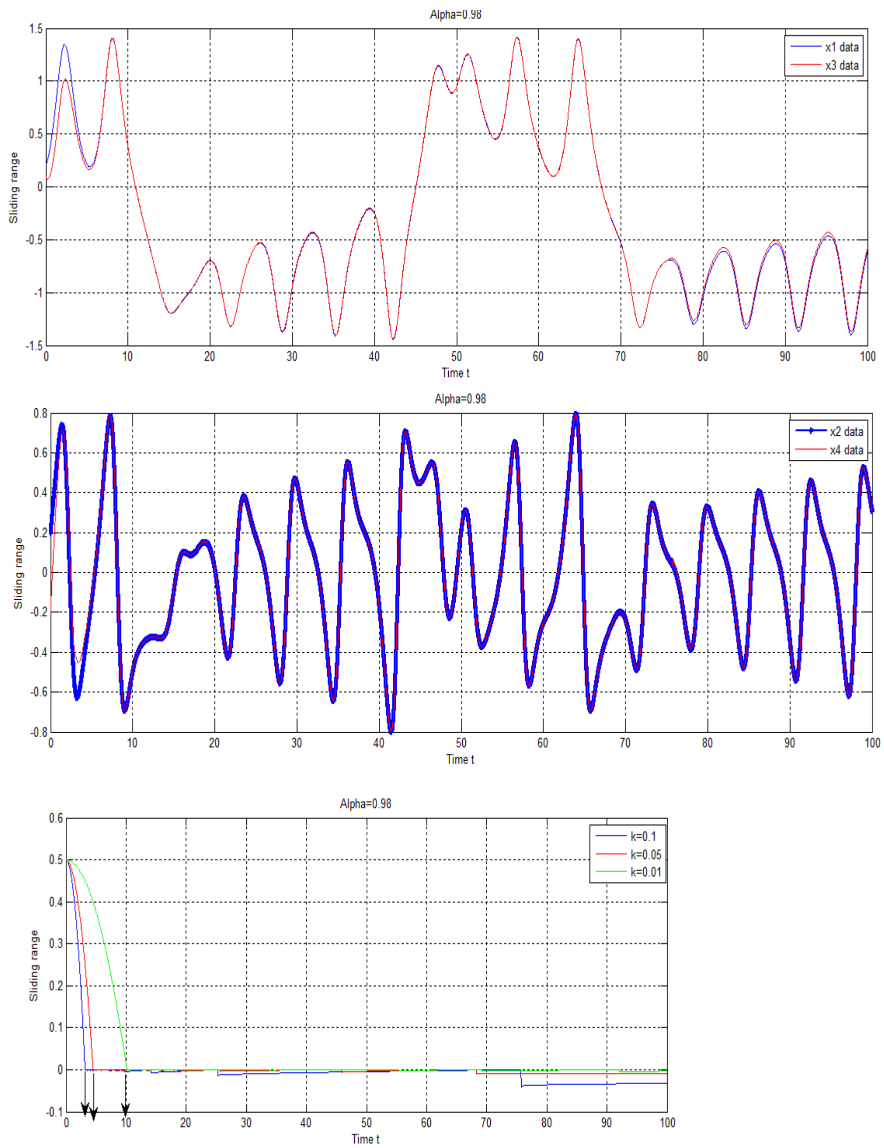


Figure 8.6: Synchronize and sliding graph q=0.98

Chapter 9

Synchronization Of Fractional Order With Integer Order Of System Using Smc

9.1 Simulation result of Chua's system

we have study chua's circuit which is an ideal circuit.the circuit consist of two capacitors inductor resistor R and chua's diode(NR).by applying KCL in circuit it can be describe by following three equations[10,11].

$$\frac{dV_1(t)}{dt} = \frac{1}{C_1}[G(V_2(t) - V_1(t) - f(V_1(t))]$$
$$\frac{dV_2(t)}{dt} = \frac{1}{C_2}[G(V_1(t) - V_2(t) - I_L(t)]$$
$$\frac{dI_L(t)}{dt} = \frac{1}{L}[-V_2(t) - R_L I_L(t)]$$

In simulation we have take different order of the system than we have done different simulation with help of fde 12 method and differential equation of our system.

In above fig is depicted chaotic attractor of the integer-order Duffings system for the following parameters =10, with initial conditions (x(0),y(0),z(0)) = (-3,-2,3) for simulation time Tsim = 100s and time step h = 0.005 In above fig is depicted the limit cycle of the integer and fractional order chua's syatem[19].

In second case we have change value of q and run the differential equation in matlab with help of fde12 method which is use for derive fractional or-

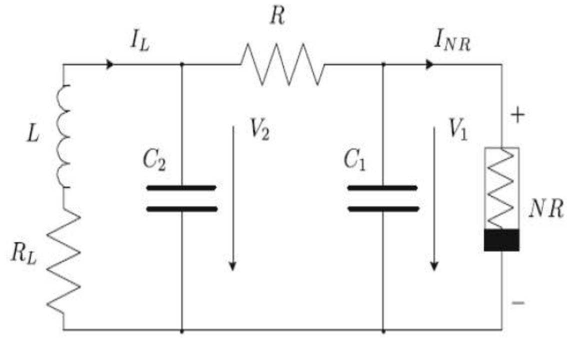


Figure 9.1: Simple chua's circuit

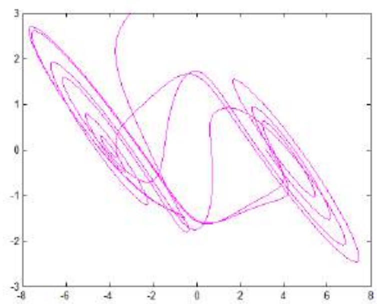


Figure 9.2: Chua's simulation result for q=1

der differential equations.Phase trajectory (attractor) in plane xy for the integer-order chuas system with parameters = 10 and initial conditions (x(0),y(0),z(0)) = (-3,-2,3).In above Fig is depicted the limit cycle of the fractional and integer order Chua's system[13,14].

In third case we have change value of q and run the differential equation in matlab with help of fde12 method which is use for derive fractional order differential equations.Phase trajectory (attractor) in plane xy for the integer-order Chuas system with parameters = 10 and initial conditions (x(0),y(0),z(0)) = (-3,-2,3).In above Fig is depicted the limit cycle of the fractional and integer order Chua's system[16,17].

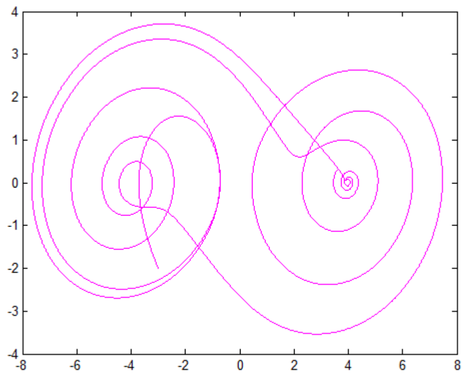


Figure 9.3: Chua's simulation result q=0.98

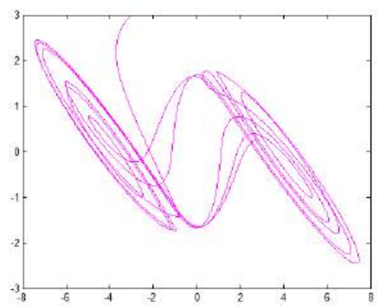


Figure 9.4: Chua's simulation result q=0.97

9.2 SMC and Synchronization of integer order and fractional order Chuas systems

We present a fractional order Chua's circuit that behaves chaotically based on the use of a fractional order low pass filter. Next, an integer order robust observer will be designed to synchronize the fractional order Chua's circuit as well as integer order Chua's circuit with unknown nonlinearity.For continuous time nonlinear dynamical systems, it has been shown in,that an integer-order unforced system must have a minimum order of three for chaos to appear. While in periodically excited systems a degree of two is enough to chaotic behavior to occur.The aim of the present work is two folds. We first present a practical way to obtain a fractional order Chua's circuit and second, we design a robust observer to synchronize the fractional order as well as the integer order Chua's systems.Next, we attempt to design a synchronization method based on robust observers in order to synchronize Chua's systems with unknown nonlinearity[26].

In synchronization task, there are a particular dynamic system as master and another different dynamic as slave. From the view point of control, the task is to design a nonlinear controller which obtains signals from the master to tune the behaviour of the slave. Let us consider master and slave with fractional order derivative equations respectively for integer order we take q=1 and for fractional order we have take q=0.98,0.97 and we will synchronize system using SMC[17,18]

$$d.^q x1 = x2 \tag{9.1}$$

$$d.^q x2 = x1 - x2 + x3 \tag{9.2}$$

$$d.^q x3 = \alpha(x2 - x3 - g(x2) \tag{9.3}$$

In second case we can take q=0.98,0.97 and add disturbance in our system.Equation for second system is given below

$$d.^q x4 = x5 \tag{9.4}$$

$$d.^q x5 = x4 - x5 + x6 \tag{9.5}$$

$$d.^q x6 = \alpha(x2 - x3 - g(x2)) + d(t) + u(t) \tag{9.6}$$

d(t)is an acting disturbance against the performance of the system. A sliding mode control is proposed to provide the control input u(t) we have taken g(x2)=-4tanh(x(1)) k=gain

$$d(t) = 0.1sin(t) \tag{9.7}$$

u(t)=k*e1+e2+e3 e1=x1-x4 e2=x2-x5 e3=x3-x6

9.3 Simulation result and synchronization of Chua's system

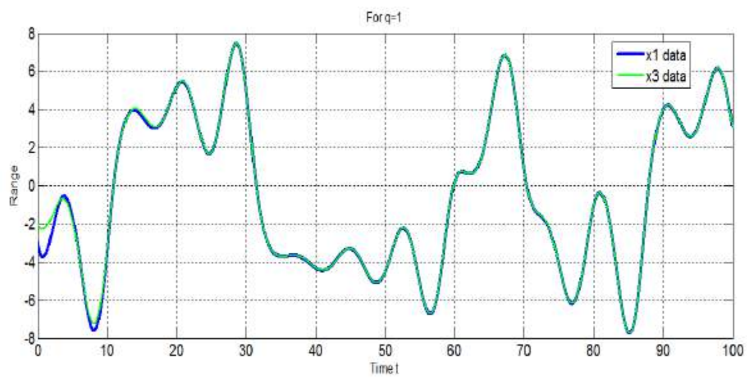


Figure 9.5: Synchronize graph e1 for q=1

In above figure we have synchronize graph of data x1 and x4 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

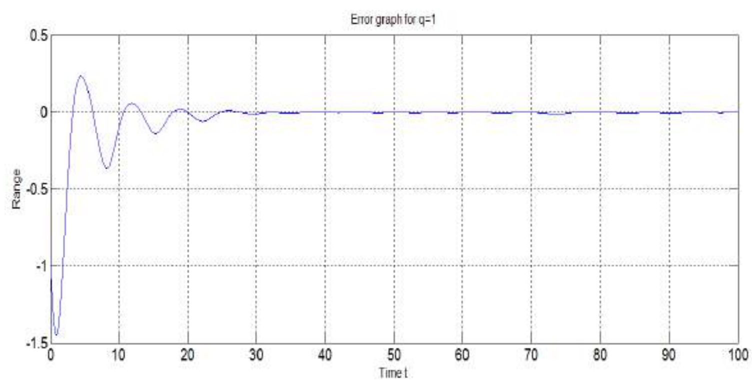


Figure 9.6: Sliding graph forq=1

In above figure it is a error graph e1 after synchronization where error is e1=x1-x4 vs time t.which is stable after 25 seconds for order q=1.

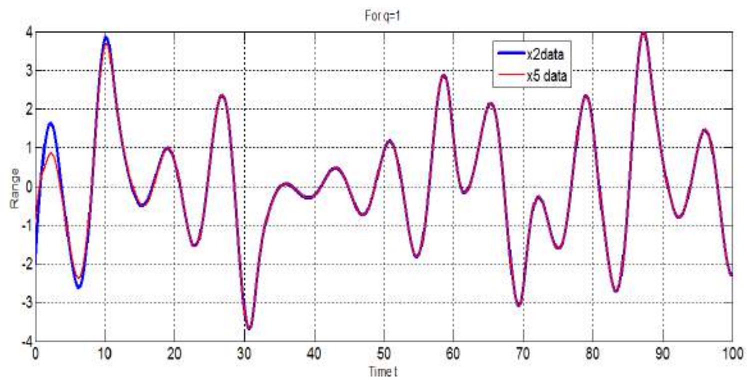


Figure 9.7: Synchronize graph e2 q=1

In above figure we have synchronize graph of data x2 and x5 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

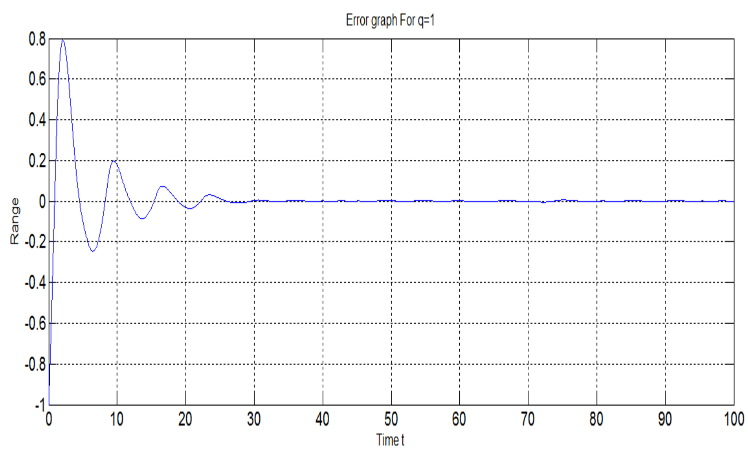


Figure 9.8: Sliding graph for q=1

In above figure it is a error graph e2 after synchronization where error is e2=x2-x5 vs time t.which is stable after 30 seconds for order q=1.

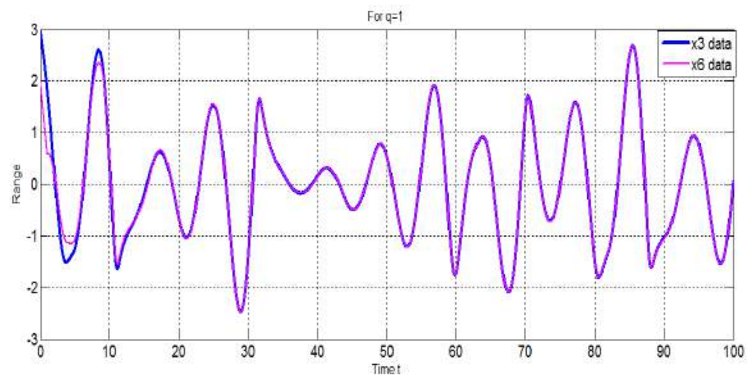


Figure 9.9: Synchronize graph e3 for q=1

In above figure we have synchronize graph of data x3 and x6 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

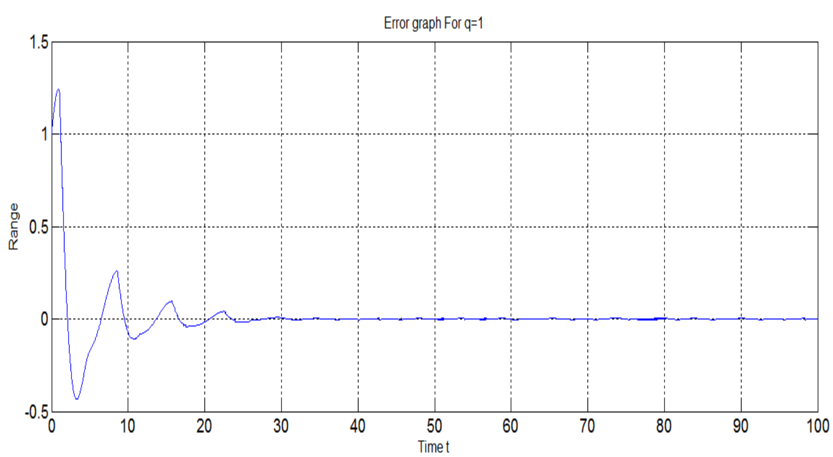


Figure 9.10: Sliding graph for q=1

In above figure it is a error graph e3 after synchronization where error is e3=x3-x6 vs time t.which is stable after 28 seconds for order q=1.

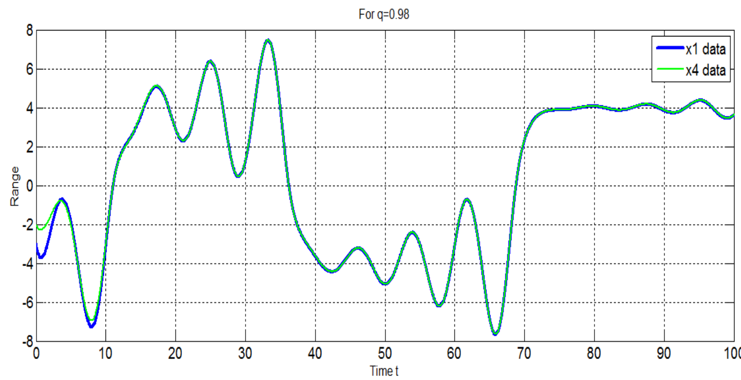


Figure 9.11: Synchronize graph e1 q=0.98

In above figure we have synchronize graph of data x1 and x4 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

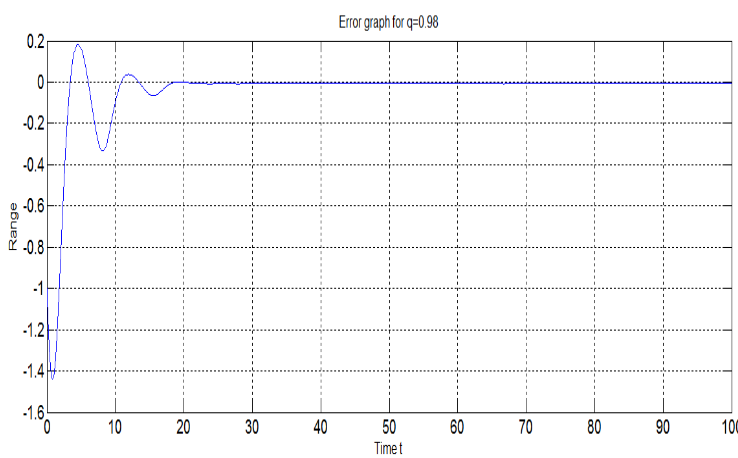


Figure 9.12: Sliding graph for q=0.98

In above figure it is a error graph e1 after synchronization where error is e1=x1-x4 vs time t.which is stable after 17 seconds for order q=0.98.

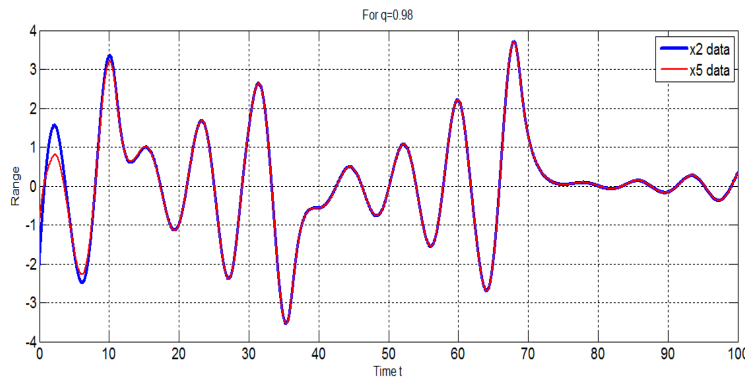


Figure 9.13: Synchronize graph e2 q=0.98

In above figure we have synchronize graph of data x2 and x5 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

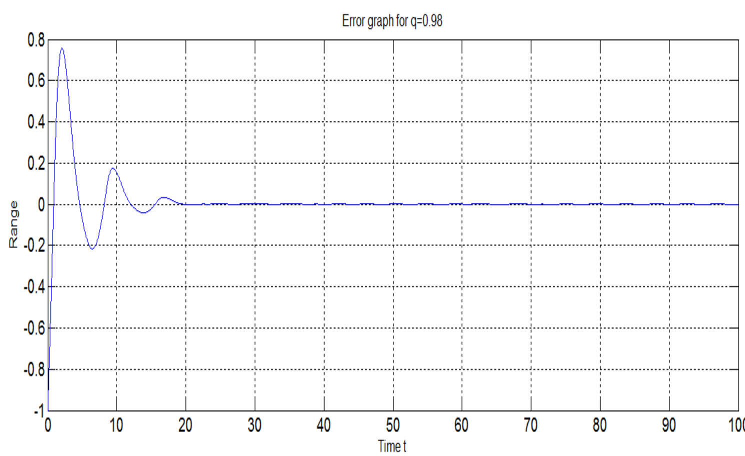


Figure 9.14: Sliding graph for q=0.98

In above figure it is a error graph e2 after synchronization where error is e2=x2-x5 vs time t.which is stable after 20 seconds for order q=0.98.

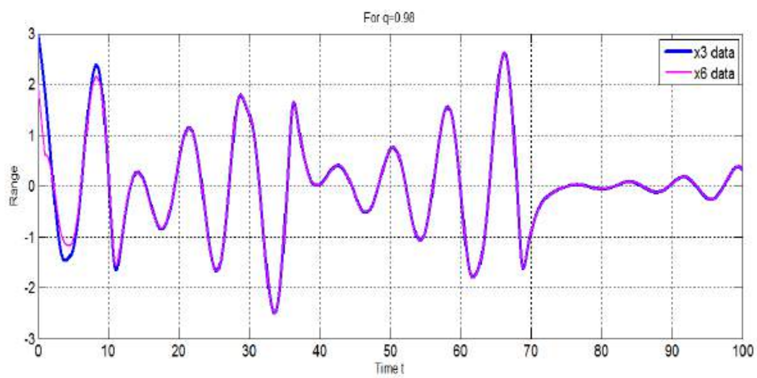


Figure 9.15: Synchronize graph e3 q=0.98

In above figure we have synchronize graph of data x3 and x6 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

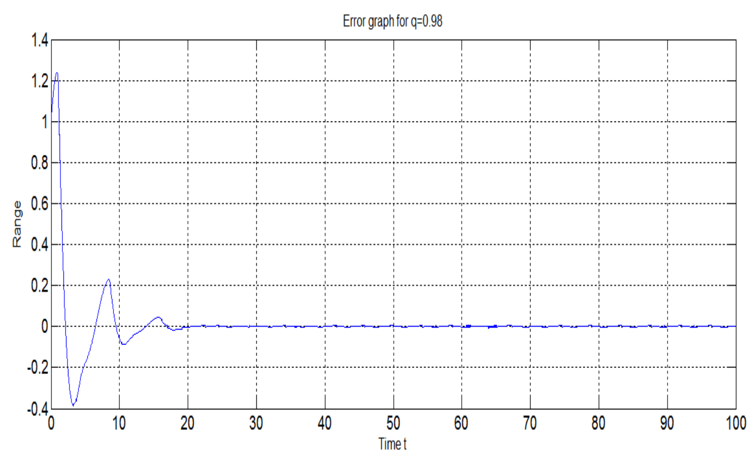


Figure 9.16: Sliding graph for q=0.98

In above figure it is a error graph e3 after synchronization where error is e3=x3-x6 vs time t.which is stable after 19 seconds for order q=0.98.

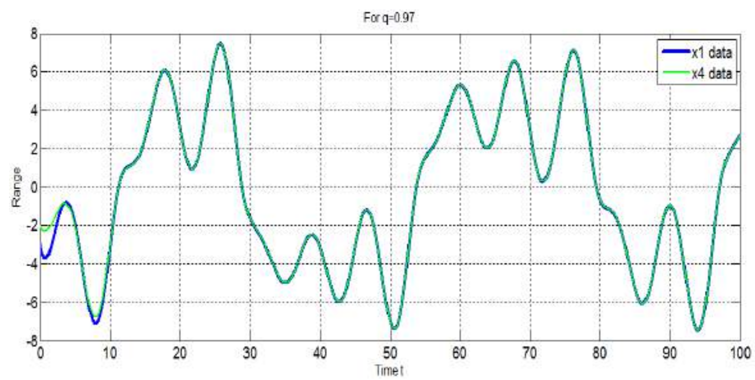


Figure 9.17: Synchronize graph e1 q=0.97

In above figure we have synchronize graph of data x1 and x4 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

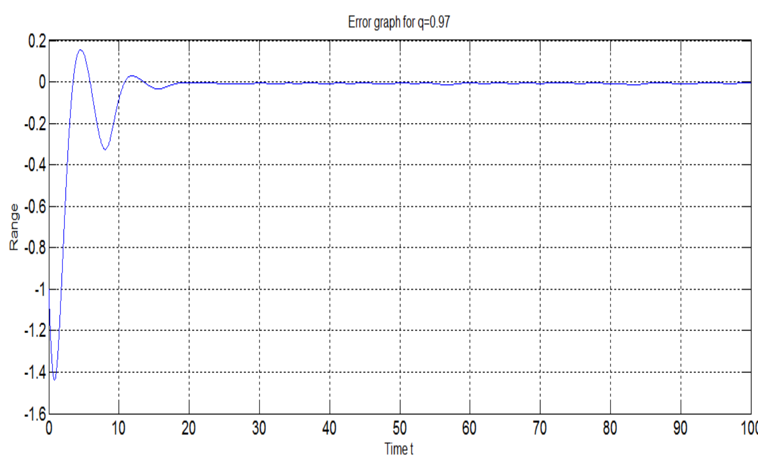


Figure 9.18: Sliding graph for q=0.97

In above figure it is a error graph e1 after synchronization where error is e1=x1-x4 vs time t.which is stable after 18 seconds for order q=0.97.

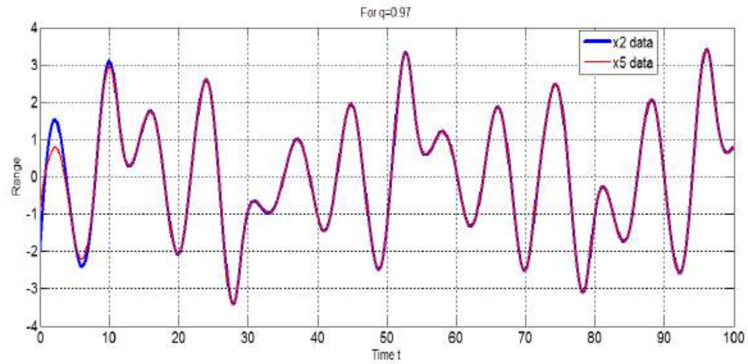


Figure 9.19: Synchronize graph e2 q=0.97

In above figure we have synchronize graph of data x2 and x5 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

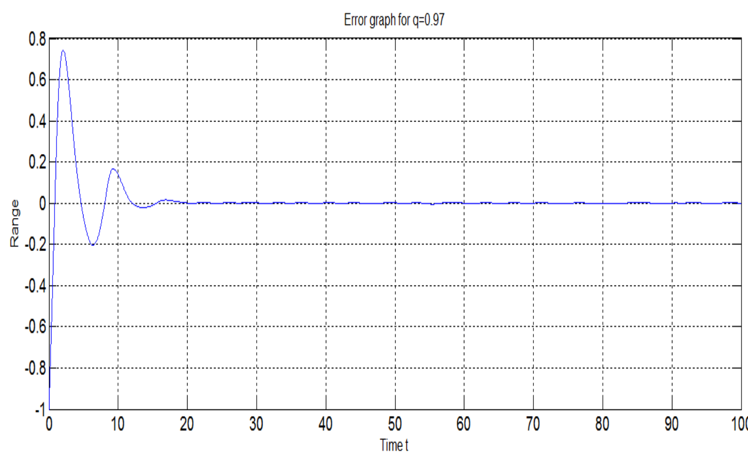


Figure 9.20: Sliding graph for q=0.97

In above figure it is a error graph e2 after synchronization where error is e2=x2-x5 vs time t.which is stable after 19 seconds for order q=0.97.

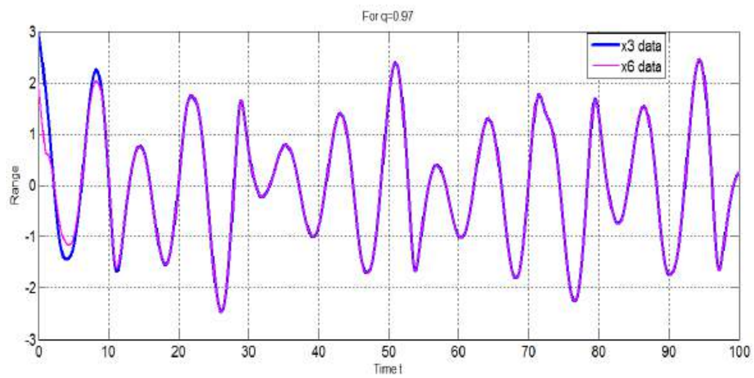


Figure 9.21: Synchronize graph e3 q=0.97

In above figure we have synchronize graph of data x3 and x6 after adding control law and disturbance.it has little effect on output.they are synchronize and system become robust so after some time disturbance does not affect system out put.

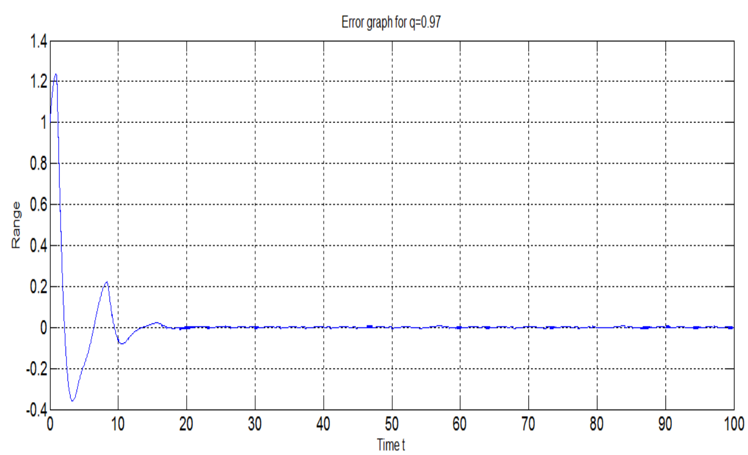


Figure 9.22: Sliding graph for q=0.97

In above figure it is a error graph e3 after synchronization where error is e3=x3-x6 vs time t.which is stable after 18 seconds for order q=0.97.

Chapter 10

Conclusion and Future work

10.1 Conclusion

The modelling of the nonlinear chaotic system can easily carried out by fractional differential equations. It has been found that the condition of chaos can be determined by the fractional order value of the differential equations. The various simulations prove the importance of fractional order modelling for nonlinear systems. The identification of fractional order systems is still an open problem. The hardware implementation of the fractional order Chuas circuit has been done to verify the chaos nature of the system.
The sliding mode technique is found to be most suitable technique for the synchronization problems. The synchronization of the two fractional order chaotic systems has been achieved through the sliding mode controller. The sliding mode control technique is also applied to synchronize the fractional order system with integer order system.

10.2 Future work

The real time hardware implementation of chaotic systems along with synchronization technique can be carried out further to validate the theoretical simulations. A practical way to identify the fractional order nonlinear system can be considered as part of identification problem.

Chapter 11

References

1. Implementation of the Chuas circuit and its applications Mahesh Mulukutla and Cherif Aissi;University of Louisiana at Lafayette, College of Engineering Lafayette,USA,March 20-22, 2002

2. Method for simulation of the fractional order chaotic systems,Acta Montanistica slovaca,Ivo Petras,2006

3. Numerical Simulation Chaotic Synchronization of Chua Circuit and Its Application for Secure Communication Mustafa Mamat, Mada Sanjaya W.S and Dian Syah Maulana,Applied Mathematical Sciences, Vol. 7, 2013,

4. Fractional Derivatives, Fractional Integrals, and Fractional Differential Equations in Matlab Ivo Petras Technical University of Koice Slovak Republic

5. Fractional order nonlinear systems modeling,analysis,simulation by Ivo Petras

6. L. O. Chua et al, A Universal Circuit for Studying and Generating Chaos-Part II Strange Attractors, IEEE Transaction on Circuit and Systems , vol 40, pp745-762,October 1993

7. Wajdi M. Ahmad ,J.C. Sprott Chaos in fractional-order autonomous nonlinear systems Elsevier, Chaos, Solutions and Fractals vol16, pp339-351, September ,2003

8. S.H. Hosseinnia,R. Ghaderi, Ranjbar N., M. Mahmoudiana, S. Momanic Crown "Sliding mode synchronization of an uncertain fractional order chaotic sys-tem"Copyright 'Published by Elsevier Ltd.,pp1637-1643,2010

9. Danial Mohammadi Senejohnny,Hadi Delavari "Active sliding observer scheme based fractional chaos synchronization",Elsevier,pp4343-4383, March,2012

10. Ichraf El Gammoudi,and Moez Feki "Synchronization of integer order and fractional order Chua's systems using robust observer",Elsevier,pp625-638,August,2012

11. Moez Feki and Rihab Gain "Synchronizing Fractional Order Chaotic Systems With An Integer Order Observer ", International Multi Conference on Systems, Signals and Devices,IEEE,2011

12. Sandip A mehta and Snehal J Panchal "Nonlinear And Nonlinear Fractional Order Chaotic System Identification and comparison Between Two Chaotic Systems",Nirma University International Conference on Engineering,2013

13. M. Srivastava, S.K. Agrawal, K. Vishal, S. Das "Chaos control of fractional order RabinovichFabrikant system and synchronization between chaotic and chaos controlled fractional order RabinovichFabrikant system",Science direct, 21st November,2013

14. A.G.Radwan,K.Moaddy,K.N.Salama,S.Momani,I.Hashim "Control and switching synchronization of fractional order chaotic systems using active control technique",Journal of advance research,pp125-132,march,2013

15. Sachin Bhalekar,Varsha Daftardar-Gejji "Synchronization of different fractional order chaotic systems using active control",Elsevier,pp3536-3546,January,2010

16. Abolhassan Razminia,Dumitru Baleanu "Complete synchronization of commensurate fractional order chaotic systems using sliding mode control", Elsevier,pp873-879,March,2013

17. A.S.Hegazi,A.E.Matouka"Dynamical behaviors and synchronization in the fractional order hyper chaotic Chen system"// Elsevier,pp1938-1944,May,2011

18. Chunlai Li,Kalin Sua,Yaonan Tongb,Hongmin Li"Robust synchronization for a class of fractional-order chaotic and hyperchaotic systems", Elsevier,pp3242-3245,October,2012

19. T.T.Hartley,C.F.Lorenzo,H.K.Qammer,"Chaos in a fractional order Chua's system",IEEE,pp485-490,1995.

20. Wikipedia (EN), http://en.wikipedia.org/wiki/Nonlinear system

21. Wikipedia (EN), http://en.wikipedia.org/wiki/Chua 27 circuit

22. http://www.academypublisher.com/jcp/vol03/no01/jcp03013239.pdf

23. http://ir.lib.nthu.edu.tw/bitstream/987654321/17659/1/2030226030023.pdf

24. http://www.ewh.ieee.org/soc/e/sac/meem/index.php/meem/article/viewFile/46/58

25. http://www.hse.gov.uk/nuclear/software.pdf

26. http://www.engineeringletters.com/issues v16/issue 3/EL16/3/07.pdf

27. http://www.chuacircuits.com

Annexure

Undertaking for Originality of the Work

I,**Snehal kumar J Panchal, Roll.No.12micc10**, give undertaking that the Major Project entitled **"Identification And control of Nonlinear Chaotic Systems"** submitted by me, towards the partial fulfillment of the requirements for the degree of **Master of Technology in Control and Automation** of Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

Signature of Student

Date:

Place: Ahmedabad

Endorsed by

(Signature of Guide)

Publication On The Work

Snehal J Panchal,Mr.Sandip A Mehta,**"Nonlinear And Nonlinear Fractional Order Chaotic System Identification and comparison Between Two Chaotic Systems"**,Nirma University International Conference on Engineering,2013