Chen System

1.1 Introduction

Edward Lorenz described a simple mathematical model for atmospheric convection in 1963 [11]. It is now the most common example of a chaotic attractor that emerges for specific parameter and beginning value values. Lorenz equations can also be found in models of lasers, dynamos, thermosyphons, electric circuits, chemical reactions, and other phenomena.[36]

The following general Lorenz system is:

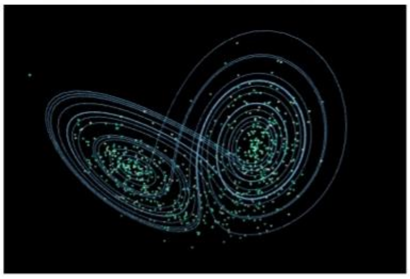
The Lorenz equations

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = \rho x - y - xz$$

$$\frac{dz}{dt} = xy - \beta z$$

The Lorenz attractor (σ=10, ρ=28, β=8/3)



the Lorenz system has chaotic solutions and the set of chaotic solutions make up the renowned Lorenz attractor. When plotted, it looks like a butterfly.

Tien-Yien Chen, discovered a chaotic attractor that is comparable but not the same as the Lorenz attractor in 1999. A parametric family of three-dimensional chaotic dynamical systems that includes the chaotic Lorenz and Chen system for parameter boundary values.

The continuing transition (or homotopy) from Lorenz to Chen illustrated there is maybe surprisingly straightforward and validates our understanding of broad similarities of both systems, despite the fact that the Chen and Lorenz attractors have different structure and attributes.

The system's equations describe the evolution of three state variables, typically denoted as x, y, and z, over time. The Chen system has been used in a variety of fields, including chaos theory, secure communications, and cryptography. Its attractor is a set of points or a region in phase space that the system tends to approach over time, which is a fundamental concept in dynamical systems. The attractor of the Chen system exhibits remarkable traits, such as chaotic behavior, self-similarity, and sensitive dependency on beginning conditions.

We intend to investigate the dynamics of the Chen system and the properties and implications of its attractor.[37]

Chen developed a new chaotic system, the Chen chaotic system, so called by other researchers, This system is described by

$$\frac{dx}{dt} = \alpha x - yz$$

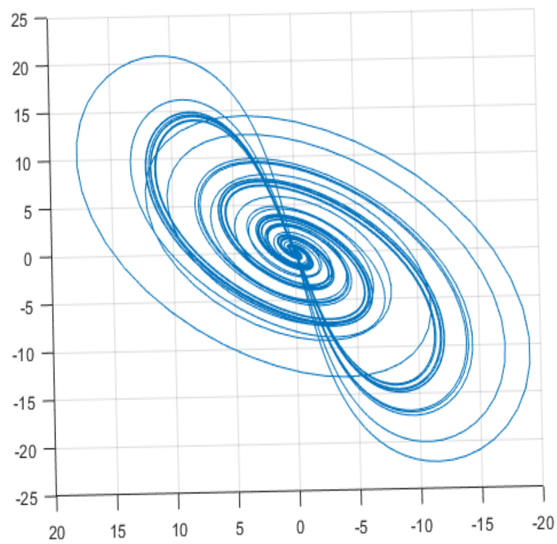
$$\frac{dy}{dt} = \beta y + xz$$

$$\frac{dz}{dt} = \delta z + \frac{xy}{3}$$

With parameters as: α=5, β=−10, δ=−0.38

4.2 Simulating The Chen System

Note: The matlab code for the simulation of the Chen system is found in appendix K



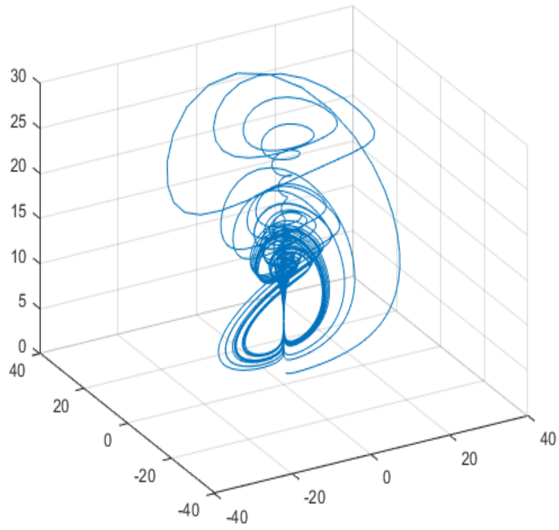


*Figure T:Periodic behaviour of Chen system

Figure Z: 2d Plot of The Chen Attractor with alpha =5 ,beta =-10 and sigma=-0.38	Figure X: 3D plot of the Chen system with alpha =5 ,beta =-10 and sigma=-0.38

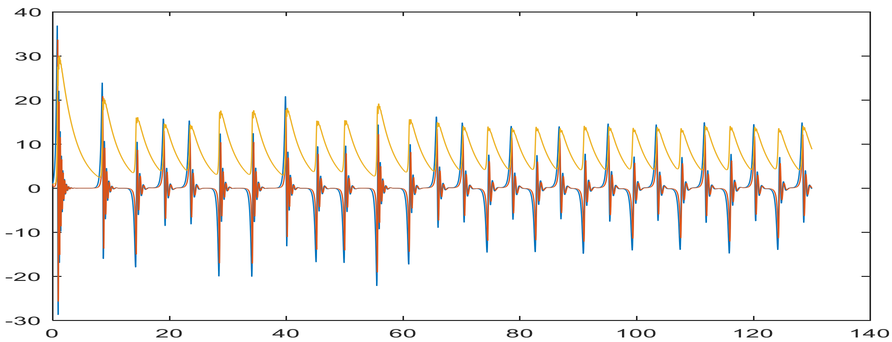
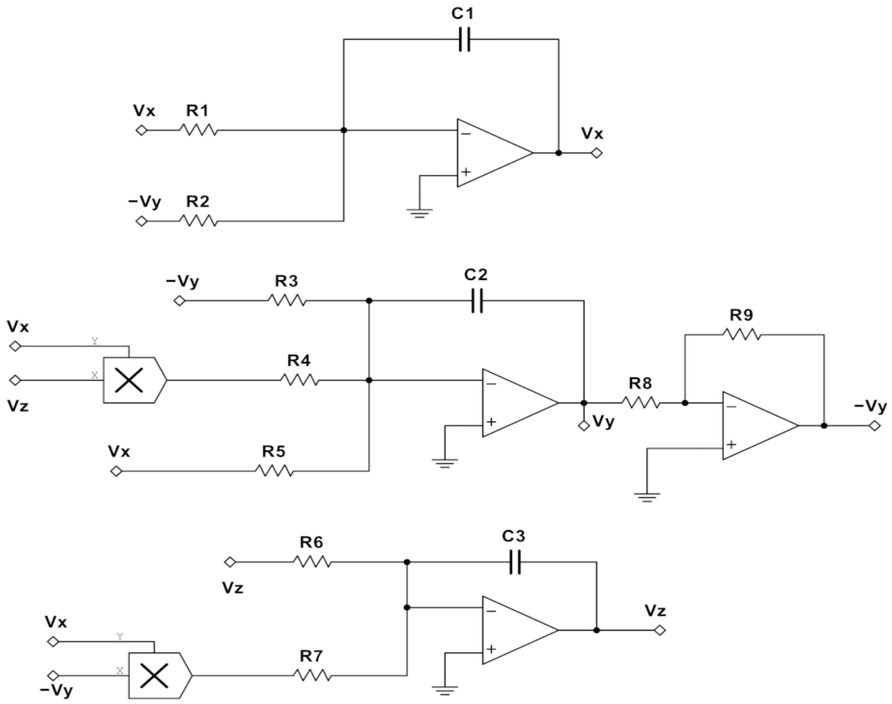


FIG T.

4.3 Applications of the chen system

The Chen system has been used in a variety of domains, including chaos theory, secure communications, and cryptography also as Chen hyper-chaotic system with a memristor [41]feedback. Its attractor is a group of points or an area in phase space that the system tends to approach over time, which is a key idea in dynamical systems. The Chen system's attractor has distinctive traits such as chaotic behaviour, self-similarity, and sensitive dependency on initial conditions.



Improved circuit diagram of the Chen system.[41]

Conclusion

Chaotic system appears to be the latest scientific revolution, opening up new avenues for understanding natural phenomena.We are learning more and more about how things transition from predictable to chaotic behavior as they continue to evolve. My research delves into the interesting world of chaotic systems and their behavior, focusing on two notable examples: the Logistics map and the Henon map. We learned about the complicated and unpredictable character of chaos by examining these systems and evaluating their accompanying graphs.

In addition, we investigated the calculation of several dimensions in order to better comprehend the complexity of chaotic systems. We learned from the logistic map and other unusual attractors that practically all naturally occurring things exhibit chaotic behavior and that systems are always bounded.. Quantitative assessments of the system's complicated structure and sensitivity to initial conditions were supplied by the fractal dimension, capacity dimension, information dimension, and correlation dimension.

Furthermore, we investigated the Chen system and its attractor, which demonstrated chaotic dynamics in three dimensions. The attractor highlighted the system's sensitivity to initial conditions as well as its potential to exhibit a variety of complicated behaviors.

The investigation of chaotic systems has yielded important insights into the intricate behavior and complex dynamics of natural and artificial phenomena. We have gained a better grasp of chaos and its applications by investigating the Logistics map, Henon map, fractal dimensions, the Chen system, and their applications. Understanding the Chen system and its attractor not only enhances our knowledge of nonlinear systems but also provides valuable insights applicable to various scientific and engineering domains. The study of chaotic systems has great promise for future advances in science, technology, and beyond.

APPENDIX:MATLAB CODE TO SIMULATE THE CHEN SYSTEM

```
ti = 0; % set the initial value of t
tf = 130; % set the final value of t
dt = 0.01;
% set the step size
xo = 5.0; yo = 10.0; zo = 10.0;
% set the initial conditions (arbitrarily)
t = [ti : dt : tf];
% creating a vector of the nodal points
N = length(t);
% calculate the number of nodes
r(:,1) = [xo ; yo ; zo];
% creating a vector with the initial conditions
for i = 1: N-1
    k1 = dt * f( t(i) , r(:,i) );
    k2 = dt * f( t(i)+dt/2 , r(:,i)+k1/2);
    k3 = dt * f( t(i)+dt/2 , r(:,i)+k2/2);
```

```
    k4 = dt * f( t(i)+dt , r(:,i)+k3);
    r(:,i+1) = r(:,i)+(k1+2*k2+2*k3+k4)/6;
end
figure(1),plot(t,r(1,:),t,r(2,:),t,r(3,:))
figure(2),plot3(r(1,:),r(2,:),r(3,:)),grid on
clear t
x=r(1,3002:N)';
y=r(2,3002:N)';
z=r(3,3002:N)';
clear r
figure(3),plot3(x,y,z),grid on
function [rdot] = f (t, r)
    sigma   = -0.38;
    alpha   = 5;
    beta    = -10;
    x       = r(1);
    y       = r(2);
    z       = r(3);
    rdot    = zeros(3,1);
    rdot(1) = alpha * x - y * z;
    rdot(2) = beta * y + x * z;
    rdot(3) = sigma * z + (x * y) / 3;
end

% existing code for chen system simulation  continues here followed by
% Compute Fractal Dimension (Capacity Dimension)
epsilon = 0.1:0.1:10; % Range of epsilon values
N_eps = length(epsilon); % Number of epsilon values
N_points = zeros(N_eps, 1); % Number of points within epsilon distance
for i = 1:N_eps
    for j = 1:length(x)
        dist = sqrt((x - x(j)).^2 + (y - y(j)).^2 + (z - z(j)).^2);
        N_points(i) = N_points(i) + sum(dist < epsilon(i));
    end
end
% Compute the capacity dimension
log_N = log(N_points);
log_eps = log(epsilon);
coeffs = polyfit(log_eps, log_N, 1);
fractal_dim = coeffs(1);
disp("Fractal Dimension (Capacity Dimension): " + fractal_dim);
epsilon = 0.1:0.1:10; % Range of epsilon values
N_eps = length(epsilon); % Number of epsilon values

N_points = zeros(N_eps, 1); % Number of points within epsilon distance
for i = 1:N_eps
    for j = 1:length(x)
        dist = sqrt((x - x(j)).^2 + (y - y(j)).^2 + (z - z(j)).^2);
        N_points(i) = N_points(i) + sum(dist < epsilon(i));
    end
end

% Compute the information dimension
log_N = log(N_points);
log_eps = log(epsilon);

coeffs = polyfit(log_eps, log_N, 1);
information_dim = -coeffs(1);
disp("Fractal Dimension (Information Dimension): " + information_dim);
```

References

[36] Anonymous(2023*), Multiscroll_attractor , viewed* on 10/07/2023,

https://en.wikipedia.org/wiki/Multiscroll_attractor

[37] Nostradamus 2013: *Prediction, Modeling and Analysis of Complex Systems*,page 305

[38] Anonymous(2023*), what-is-correlation-dimension-actually* ,viewed on 10/07/2023,

https://math.stackexchange.com/questions/4631839/what-is-correlation-dimension-actually

[39] *Sandip Thanki,(1999-07-29), correlation dimension*,viewed on 10/07/2023,

https://www.physics.unlv.edu/~thanki/thesis/node14.html

[40] Anonymous(2023), *correlationDimension,*viewed on 10/07/2023,

https://www.mathworks.com/help/predmaint/ref/correlationdimension.html

[41] Anonymous(2023), *Three-Stage-Impulse Control of Memristor-Based Chen Hyper-Chaotic System* ,viewed on 10/07/2023,

https://www.mdpi.com/2227-7390/10/23/4560