FPGA Implementation of SC-CNN Based Chaos Generator

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Abstract

In this paper, a realization of the Switch State Control Cellular Neural Network (SC-CNN)-based chaos generator using Field Programmable Gate Arrays (FPGAs) is presented. In addition, the application results compared with the simulation results.

1. Introduction

The most basic structure needed to use in chaotic based communication systems is chaotic signal generators. As hardware, chaos generators are realized as analog or digital based. The digital based chaos generators are realized by using Digital Signal Processing (DSP) [1], Application Specific Integrated Circuits (ASIC) [2] and Field Programmable Gate Array (FPGA)[3]. The ASIC-based chaos generators gives good results compared with the other structures. On the other hand, because of being not flexible and being not programmable limited the using area of this structure. Also because of the sequential operation ability, the DSP structures cannot work on high frequencies. For these reasons, having low initial cost, being flexible, being programmable, and making parallel operations foreground the FPGA structures.
These properties of FPGA-based systems have importance in the process of realization of chaos generators. In the realization of chaos generators, enable the chaos generators to produce different forms of signal according to parameter changes. Because of these features FPGA-based chaotic generator circuits can be designed flexibly and without hardware complexity.
Cellular Neural Networks-CNNs based approaches have been used frequently for the past 20 years to understand and examine complex systems, especially chaos and chaotic systems. In 1995 study ,conventional CNN was transformed in to *State Controlled-CNN (SC-CNN)* by feedback from the state points of neighboring cells, in other words transformed in to a prototype model for the modelling of complex systems [4]. The generalized dimensionless state equations and the output functions with *piecewise-linear* characteristic of *SC*-CNN are shown below.

$$\dot{x}_j = -x_j + a_j y_j + G_o + G_s + i_j,$$

$$y_j = {}^{1}\!/_{2}\left[\left|x_j + 1\right| - \left|x_j - 1\right|\right] \tag{1}$$

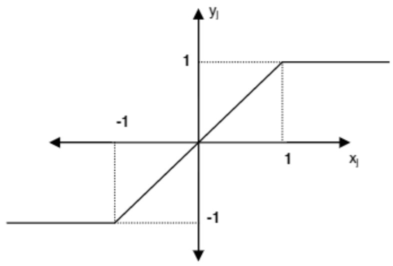


Fig. 1. *Transfer function characteristic of SC-CNN*

In equation (1) *j* shows the cell index, x_j represents state variable, y_j represents cell's output, a_j represents a constant parameter and i_j represents threshold value. Also G_o and G_s represent the outputs and state variables, respectively, of the cells associated with each other. The Proposed *SC-CNN* model differs from the original *Chua* and *Yang* definition by the G_s term [5]. In the literature SC-CNN appears to be not only in the design of many chaotic oscillators such as *Chua* circuits [6-7], *Collpitts* oscillator [8], Hyper chaotic *Saito* circuit [9], *n-double scroll* circuit [10], *MLC* circuit [11] but also in chaotic cryptography and secure communications applications [12].

2. SC-CNN-Based Chaos Generators

The common point of the above-mentioned chaotic oscillator designs is that the nonlinear output function's characteristics are univariate. These allows the implementation with *SC-CNN* which also have a single variable *piecewise-linear* characteristic. Whereas for oscillators with nonlinear characteristic functions with a multivariable structure, the univariate structure of *SC-CNN* is not sufficient. Thus in the literature the study of the design of the *Rossler* system with *SC-CNN* is an important example. As shown in equation (2) the *Rossler* system include a single nonlinear function expressed by zx[13].

$$\begin{aligned} \dot{x} &= -y - z \\ \dot{y} &= x + ay \\ \dot{z} &= zx - zc + b \end{aligned} \tag{2}$$

In equation (2) *x*,*y*,*z* represent the state variables and *a*,*b*,*c* show the parameters. The typical Rossler attractor obtained when *a*=0.2, *b*=0.2 ve *c*=5.7 are selected is shown in figure 2.

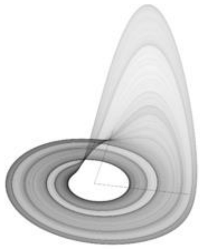


Fig 2. *Rossler* attractor [13]

In order to obtain the system given in equation (2) by using *SC-CNN* it is suggested to substitute equation (3) instead of the classical *piecewise-linear* function given in equation (1)

$$xz = (x/2 + z/2)^2 - (x/2 - z/2)^2 \quad (3)$$

The generalized version of equation (3) is given as follows.

$$y_{ij} = PWL(\sum_{i=1}^{j} D_{ij} x_{ij}) \quad (4)$$

The approach given by equations (3) and (4) suggest an extended piecewise-linear function design instead of the classical piecewise-linear function approach. In this report period study, equation (5) is proposed as an approach to solve the above situation.

$$\dot{x}_1 = -x_1 + a_{11}y_1 + a_{12}y_2 + a_{13}y_3 + s_{11}x_1 + s_{12}x_2 + s_{13}x_3 + i_1$$

$$\dot{x}_2 = -x_2 + a_{21}y_1 + a_{22}y_2 + a_{23}y_3 + s_{21}x_1 + s_{22}x_2 + s_{23}x_3 + i_2 \quad (5)$$

$$\dot{x}_3 = -x_3 + a_{31}y_1 + a_{32}y_2 + a_{33}y_3 + s_{31}x_1 + s_{32}x_2 + s_{33}x_3 + nx_3 + i_3$$

Equation (5) is proposed to model the Rossler system using the classical SC-CNN transfer function. For these purpose If equation (5) will be arranged as follows :

$$x = x_1, \quad y = x_2, \quad z = x_3, \quad a = s_{22} - 1, \quad b = i_3, \quad c = s_{33} - 1$$

$s_{11}=s_{21}=a_{11}=1$; $s_{12}=s_{13}=s_{33}=-1$; $s_{22}=1.25$;

$s_{23}=s_{31}=s_{32}=a_{12}=a_{13}= a_{21}= a_{22}= a_{23}= a_{31}= a_{32}= a_{33}=i_1=i_2=0$; $i_3=4$

$$n = \begin{cases} +1; \ y_1 \geq 0 \\ -1; \ y_1 < 0 \end{cases}$$

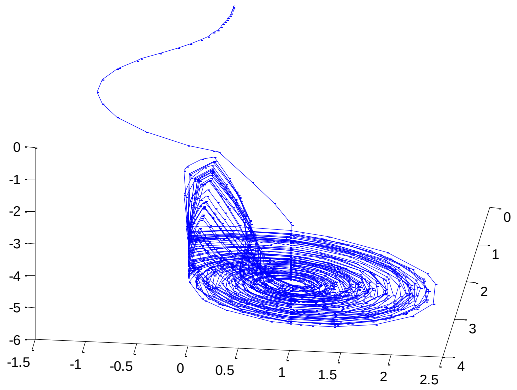
The Switch-SC-CNN based Rossler system shown in equation (6) is obtained.

$$\dot{x}_1 = -x_1 + s_{11}x_1 + s_{12}x_2 + s_{13}x_3$$

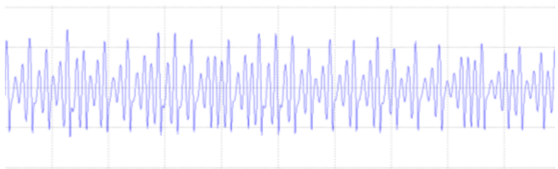
$$\dot{x}_2 = -x_2 + s_{21}x_1 + s_{22}x_2 \quad (6)$$

$$\dot{x}_3 = -x_3 + s_{33}x_3 + nx_3 + i_3$$

These new *CNN* , which can be called as *Switch-SC-CNN* , makes it possible to model multivariable system with *CNN.nx3* is used to provide *xy* nonlinear characteristic in the *Rossler* system. The value of *n* is related to the transfer function y_1 of *CNN*. Thus the value of n is set to +1 when $y_1 \geq 0$ and the value of n is set to -1 when $y_1 < 0$. In fact it will be more accurate to say n=sgn(y_1) in short. Because of *n* coefficient, the x_3 variable switched on the positive and negative axes depending on the value of classical output function of CNN. Figure 3 shows the structure of the Switch-SC-CNN–based Rossler system attractor and the time-axes numerical results of x_1 dynamics, respectively.



(a)



(b)

Fig. 3. *Switch SC-CNN-based Rossler* System a) Chaotic attractor, b) time-axes numerical results of x_1 dynamics.

The next section shows the FPGA implementation of *the S-SC-CNN*-based *Rossler* chaotic generator in addition to the numerical results.

3. FPGA Implementation of S-SC-CNN Based Chaos Generator

Chaotic Signal Generator was tried to be achieved using *DE2-1115* serial development card produced by *Altera*, the *FPGA* manufacturer, and experimental setup of the obtained generators was performed and oscilloscope images were obtained. Firstly, *HDL* codes of the dynamic system that generates the chaos to be implemented are obtained by writing in *VHDL* language. After that the obtained *HDL* codes are added to a new project created with the *FPGA* card to be used in the *Altera* compilation program *Quartus* as shown in figure 4 .

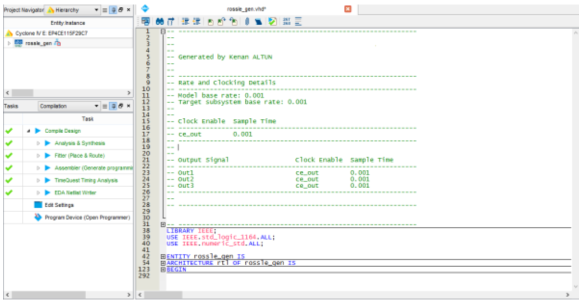


Fig. 4. *HDL* Compiling program Quartus interface

When input-output assignment of *HDL* codes compiled in *Quartus* interface is done, pin diagram is obtained and assignments are performed. Figure 5 shows the input and output pin assignments of the processor of the *Altera DE2-115* board.

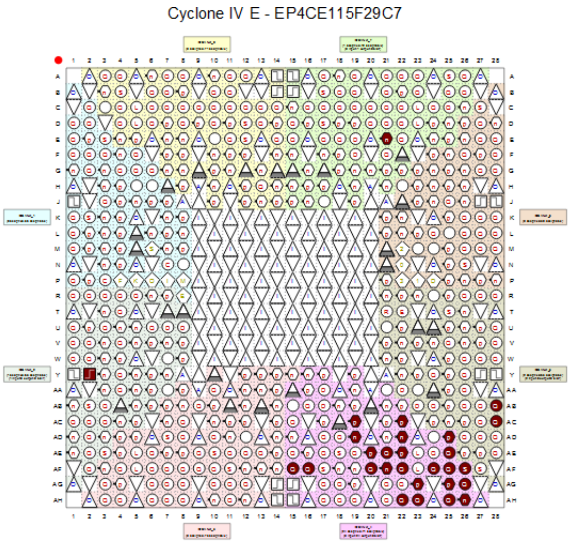


Fig. 5. *Altera DE2-115* Pin Structure

After the pin assignment is done , the recompiled *HDL* codes are loaded on the *FPGA* development board using the Quartus programmer interface shown in Figure 6.

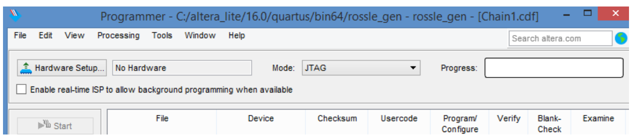
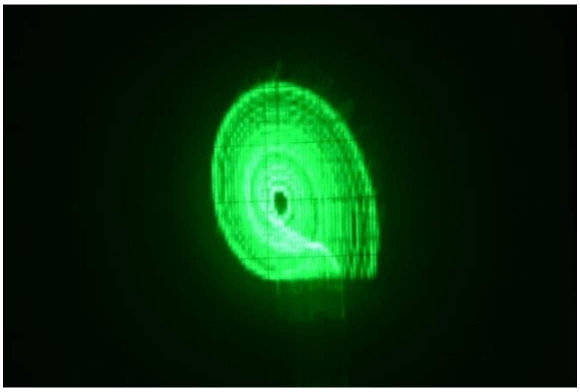
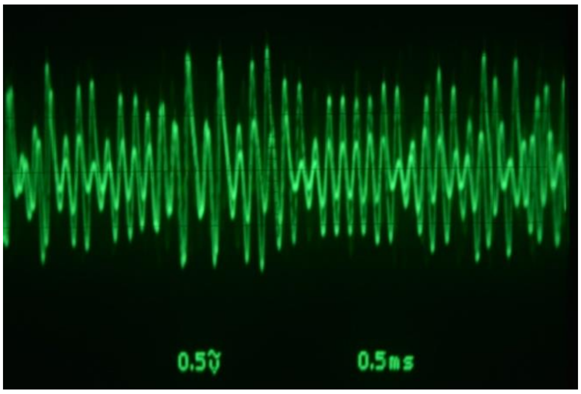


Fig. 6. Quartus Programmer

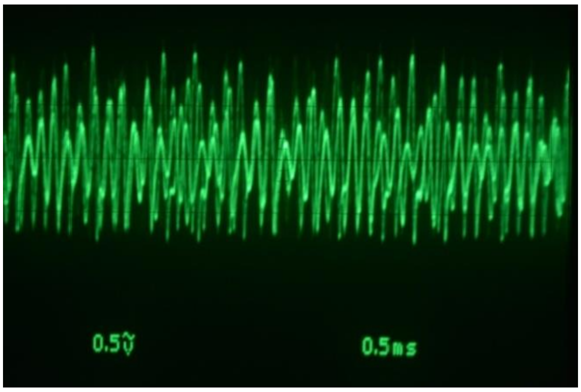
The digital outputs of the *FPGA* card are converted to analog signals by using the *DAC0808* integration. Oscilloscope images of the chaotic attractor of the *S-SC-CNN*-based *Rossler* system are shown in Figure 7 and x_1 , x_2 and x_3 dynamics, which is obtained using *ModelSim* program , are shown in Figure 8.



(a)



(b)



(c)

Fig. 7. *S-SC-CNN*-based *Rossler* System **a)** Chaotic attractor, **b)** x_1 dynamic, **c)** x_2 dynamic.

Fig. 8. The dynamics of x_1, x_2 and x_3 with *Multisim Program*

4. Conclusions

This study shows that from the known chaos generators the Rossler chaos generator can be remodeled using the S-SC-CNN structure, and shows that multivariable chaotic generators can be modeled as CNN based. Furthermore, the model obtained in the study was realized with FPGA and experimental results were revealed.

5. Information

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6. References

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