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FPGA Implementation of Synchronized Non Identical Hyperchaotic Systems

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ABSTRACT

In this paper, the FPGA Implementation of complete synchronization methodology for non-identical hyperchaotic systems using active control theory is proposed. In proposed methodology, FPGA technology is used for the synchronization of Simplified Lorentz hyperchaotic system and Pang hyperchaotic system, Xilinx system generator technology was used for the conception of synchronization of hyperchaotic systems and generating the VHDL code. This code is used to configuring a FPGA. First, Lorentz hyperchaotic system and Pang Hyperchaotic systems are implemented in FPGA. Then new results for active controllers are derived to synchronize the simplified Lorentz and Pang hyperchaotic systems completely. Finally, the active controllers and the synchronized hyperchaotic system are implemented in FPGA. The simulation outputs and experimental results are given to show the effectiveness of our proposed methodology.

Keywords: Hyperchaotic systems, complete synchronization, FPGA implementation, active control

1. INTRODUCTION

In 1990, the synchronization of identical chaotic systems with different initial conditions through a simple coupling was performed [1]. The synchronization of chaotic systems have many applications in various fields such as chemical system [2], ecological system [3], physical system [4], lasers [5], secure communication [6], cryptosystems [7], robotics [8] and neural networks [9] etc.

In the last two decades, various synchronization schemes are introduced such as, OGY method [10], active control method [11], adaptive control method [12], back stepping design method [13], sliding mode control method [14], and sampled-data feedback synchronization method [15] etc. There are various different types of synchronization such as complete synchronization [16], Anti synchronization [17], Projective synchronization [18].

Complete synchronization is characterized by the equality of state variables evolving in time, while anti-synchronization is characterized by the disappearance of the sum of relevant state variables evolving in time. In hybrid synchronization, one part of the systems is completely synchronized and the other part is anti-synchronized so that the complete synchronization and anti-synchronization co-exist in the two chaotic systems. Projective synchronization is characterized by the fact that the master and slave systems could be synchronized up to a scaling factor.

This paper deals with the FPGA implementation of complete synchronization between non-identical hyperchaotic systems with different initial conditions using active control techniques. The new results for active controller functions are derived for the Simplified Lorentz hyperchaotic system and Pang

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hyperchaotic system. The main results derived in this paper are established using Lyapunov stability theory [19].

2. FPGA IMPLEMENTATION OF SIMPLIFIED LORENTZ HYPERCHAOTIC SYSTEM

The simplified Lorentz Hyperchaotic system [20] is given by,

$$\begin{aligned}\dot{x} &= y - x \\ \dot{y} &= -xz + w \\ \dot{z} &= xy - a \\ \dot{w} &= -by\end{aligned} \tag{1}$$

Here x, y, z and w are the state variables of hyperchaotic system (1). The system (1) exhibits chaotic behavior when $a = 2.6$, $b = 0.44$. The simplified Lorentz hyperchaotic system (1) is constructed using Xilinx System Generator (XSG) block sets in MATLAB Simulink as shown in Figure 1. Then the VHDL code is generated from the system generator design and the code is used to configure the FPGA.

This implementation is adopted with a fixed point and with a representation of the real data on 32 bits, 16 for the entire and 16 for the fraction The phase portraits and time evolution of simplified Lorentz hyperchaotic system (1) for the initial conditions $\{x(0), y(0), z(0), w(0)\} = \{2, 4, 1, 3\}$are obtained using XSG technology is shown in Figure 2.

The implemented structure of the simplified Lorentz hyperchaotic system (1) in Xilinx ISE into Virtex6 xc6vsx315t-3ff1156 is shown in the Figure 3. The result of VHDL code simulation using Xilinx Isim simulator is shown in the Figure 4 which represents a portion of the waveform of state variables x, y, z and w. The signal has the numerical value. $\{x(0), y(0), z(0), w(0)\} = \{2, 4, 1, 3\}$.

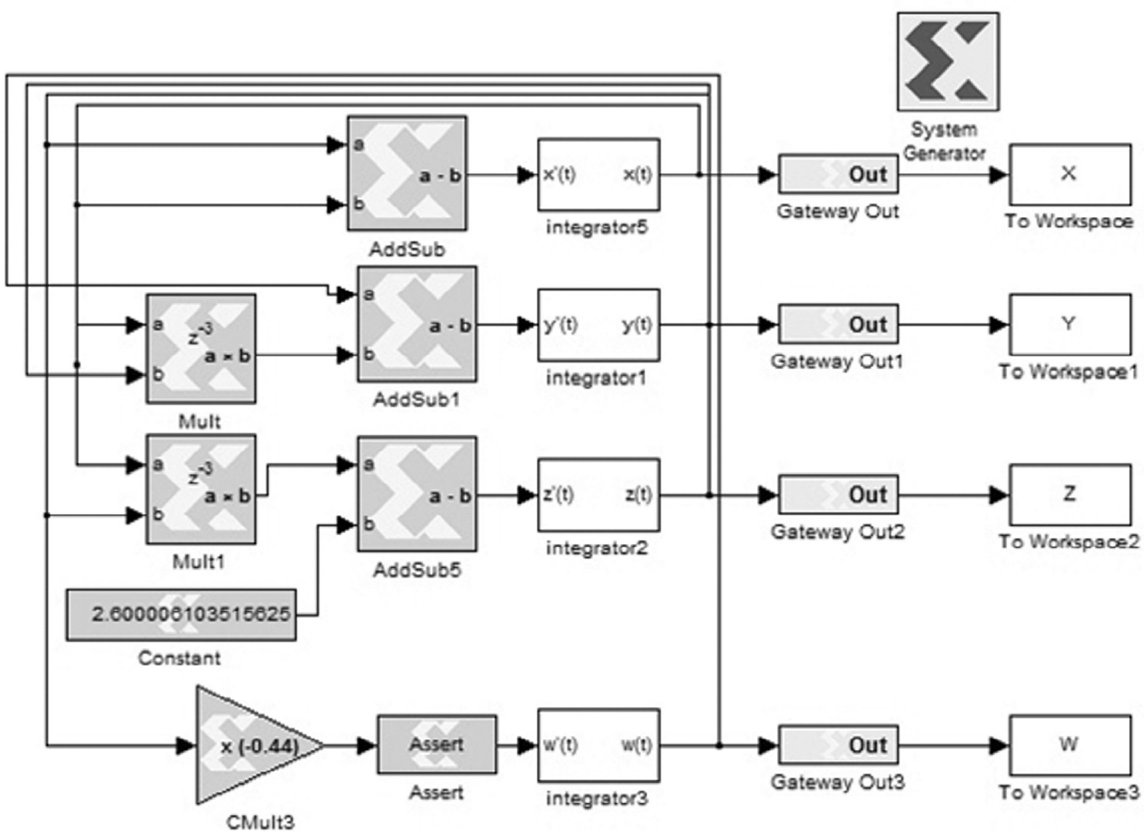


Figure 1: Implementation of Simplified Lorentz Hyperchaotic system in XSG Technology

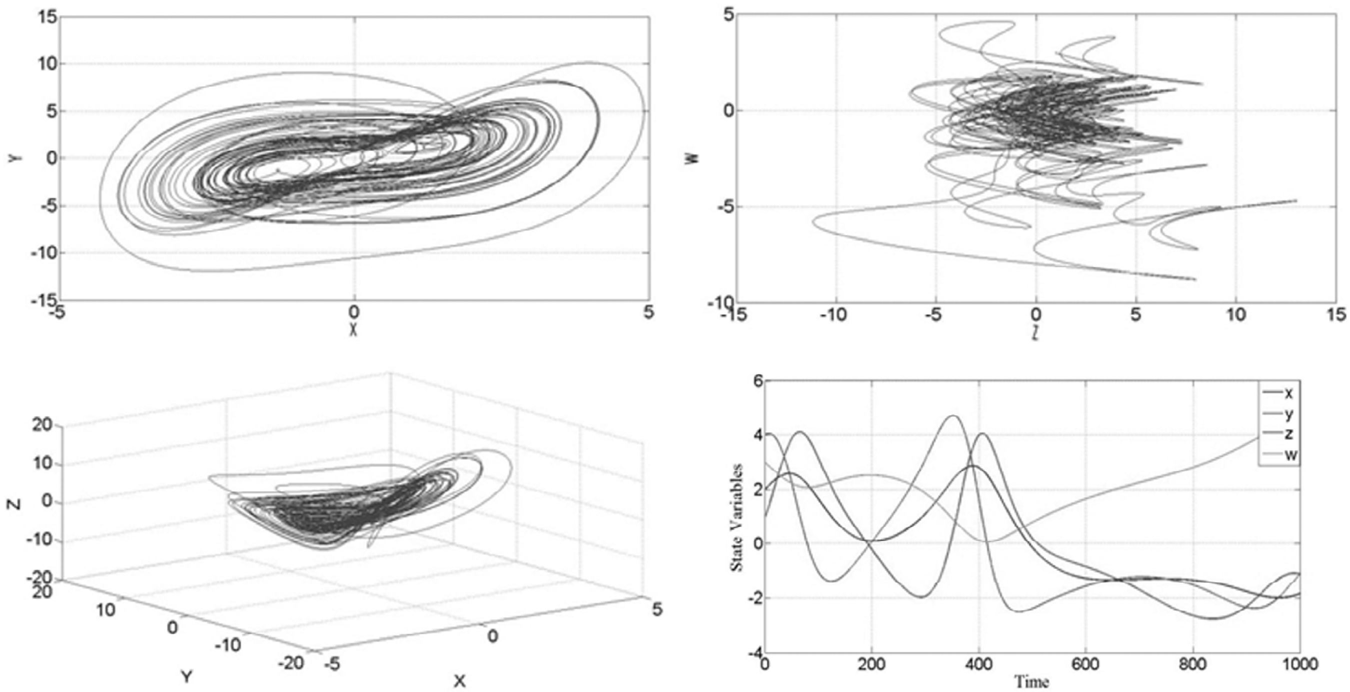


Figure 2: Phase Portraits and Time evolution of Simplified Lorentz Hyperchaotic system obtained using XSG Technology

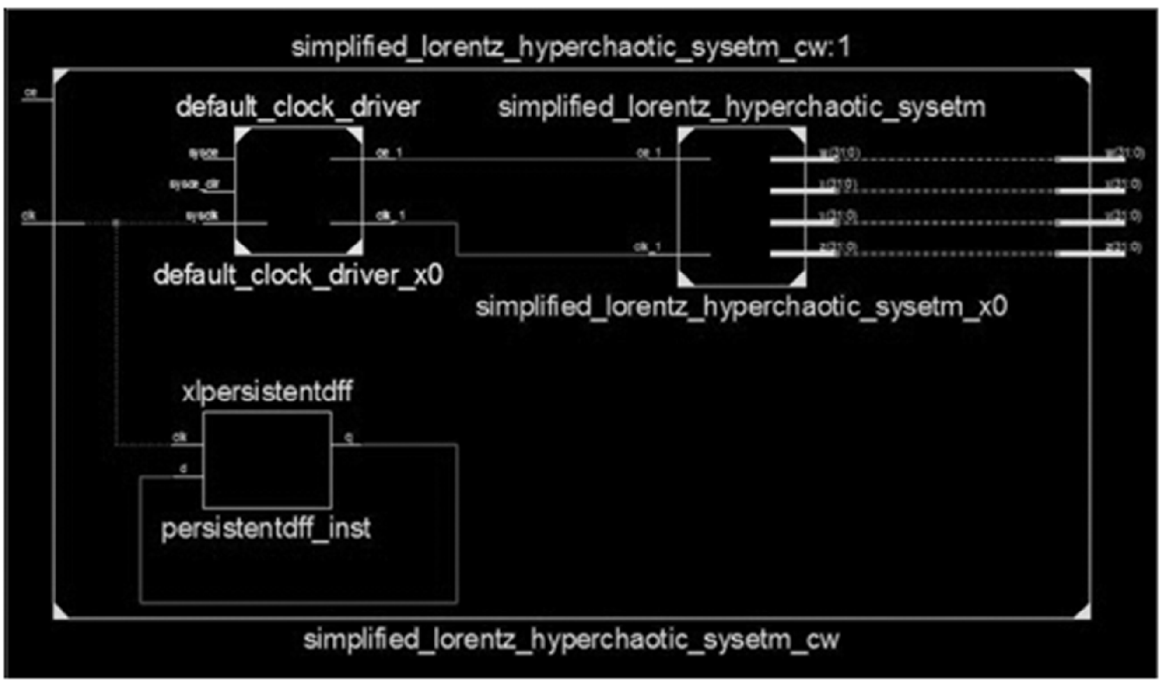


Figure 3: RTL Schematic of Simplified Lorentz Hyperchaotic system

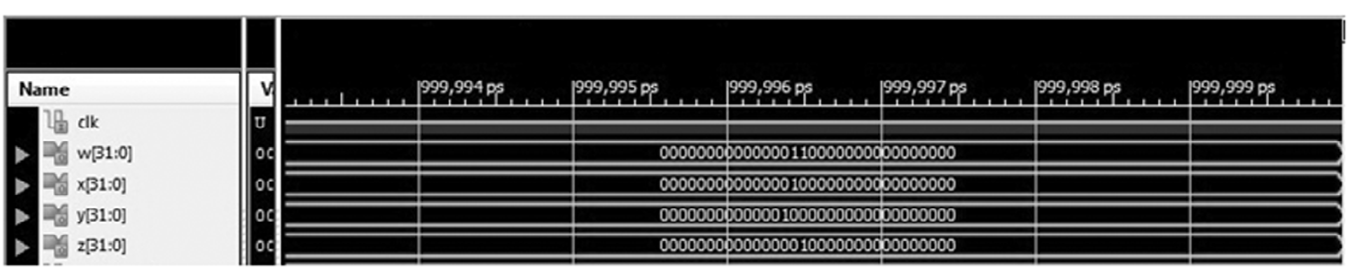


Figure 4: ISim simulation results of VHDL code for Simplified Lorentz Hyperchaotic system

3. FPGA IMPLEMENTATION OF HYPERCHAOTIC PANG SYSTEM

The hyperchaotic Pang system [21] is given by,

$$\begin{aligned} \dot{p} &= \alpha(q-p) \\ \dot{q} &= \gamma q - pr + s \\ \dot{r} &= -\beta r + pq \\ \dot{s} &= -\sigma(p+q) \end{aligned} \tag{2}$$

Here p, q, r and s are the state variables of hyperchaotic Pang system (2). The hyperchaotic Pang system exhibits chaotic behavior when $\alpha = 36$, $\beta = 3$, $\gamma = 20$ and $\sigma = 2$. The Pang system (2) is constructed using XSG block sets as shown in Figure 5.

The phase portraits and time evolution of state variables of system (2) for the initial conditions $\{p(0), q(0), r(0), s(0)\} = \{5, 6, 2, 8\}$are shown in Figure 6.

The implemented structure of the Pang hyperchaotic system (2) in Xilinx ISE into Virtex6 xc6vsx315t-3ff1156 is shown in the Figure 7. The result of VHDL code simulation using Xilinx Isim simulator is shown in the Figure 8 which represents a portion of the waveform of state variables and s. The signal has the numerical value $\{p(0), q(0), r(0), s(0)\} = \{5, 6, 2, 8\}$.

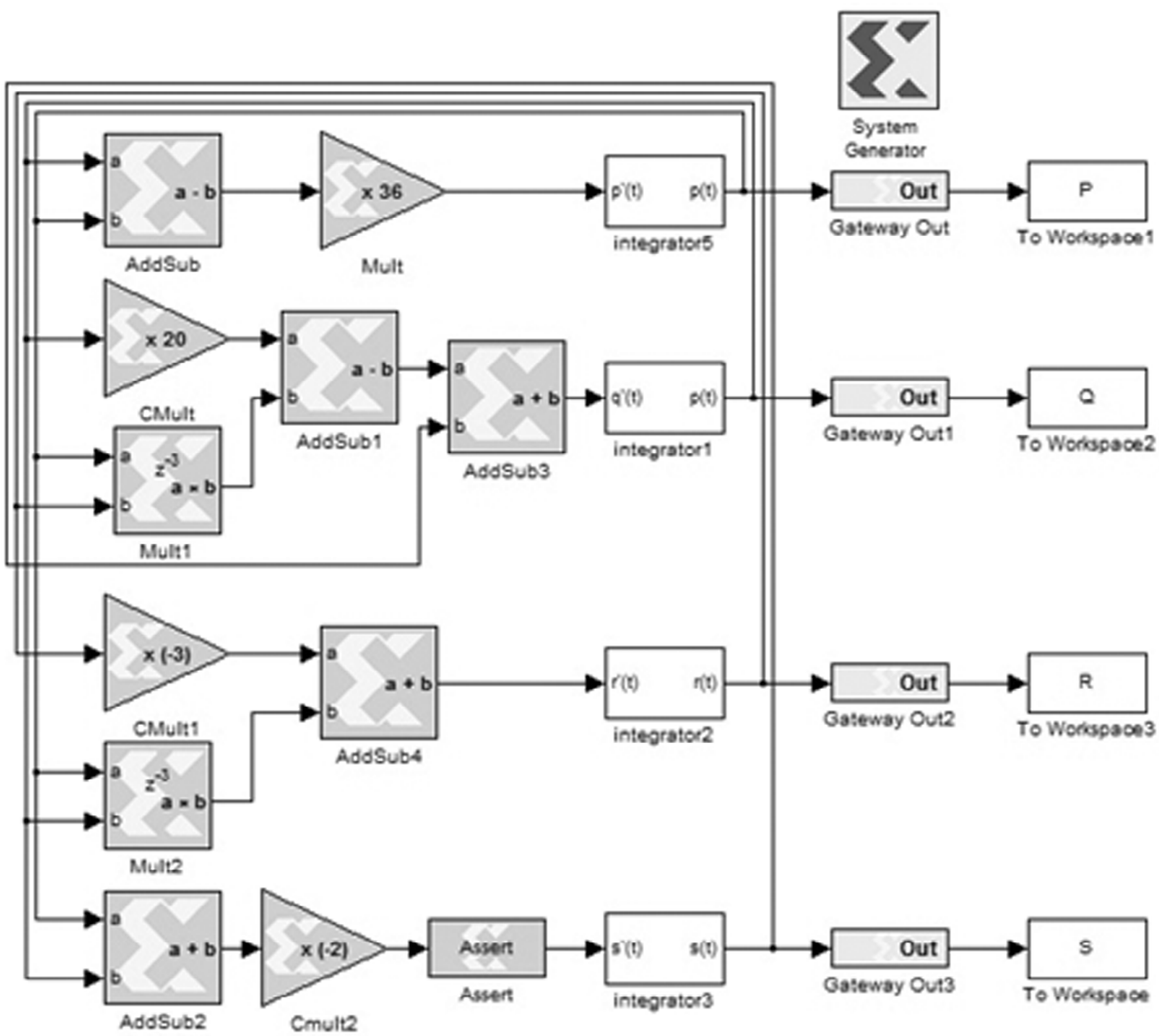


Figure 5: Implementation of Pang Hyperchaotic system in XSG Technology

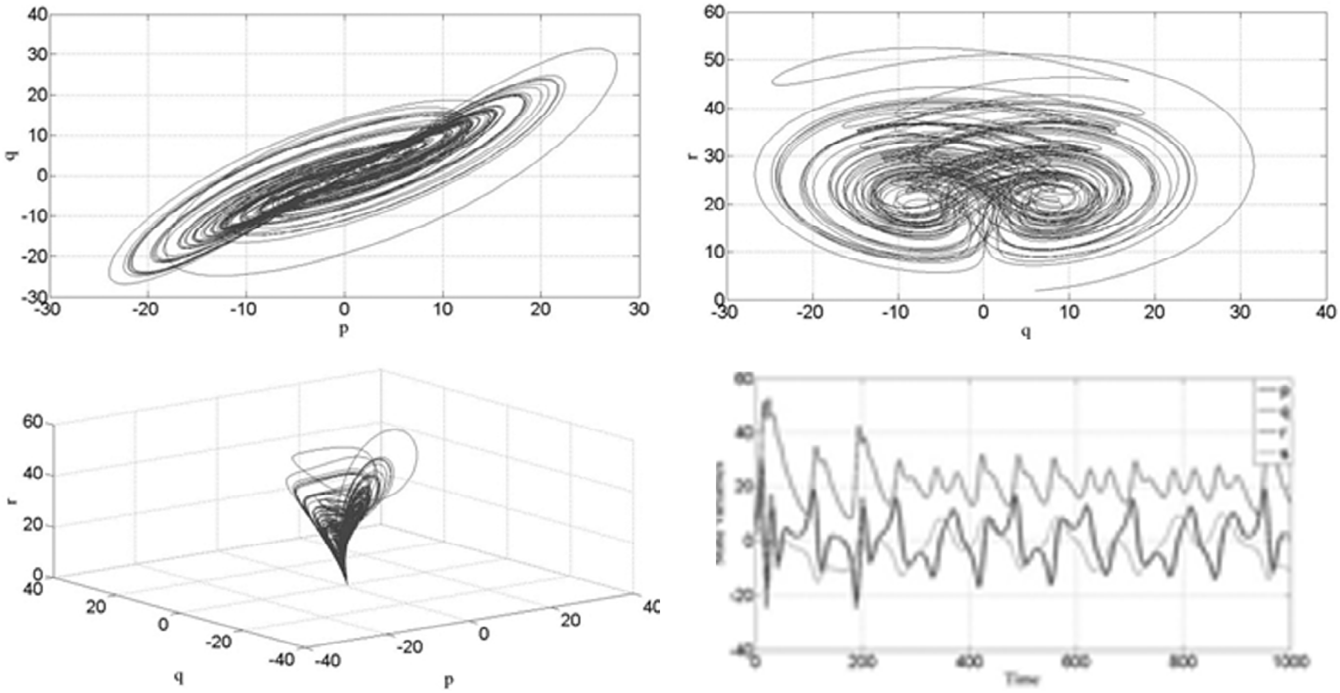


Figure 6: Phase Portraits and Time evolution of Pang Hyperchaotic system obtained using XSG Technology

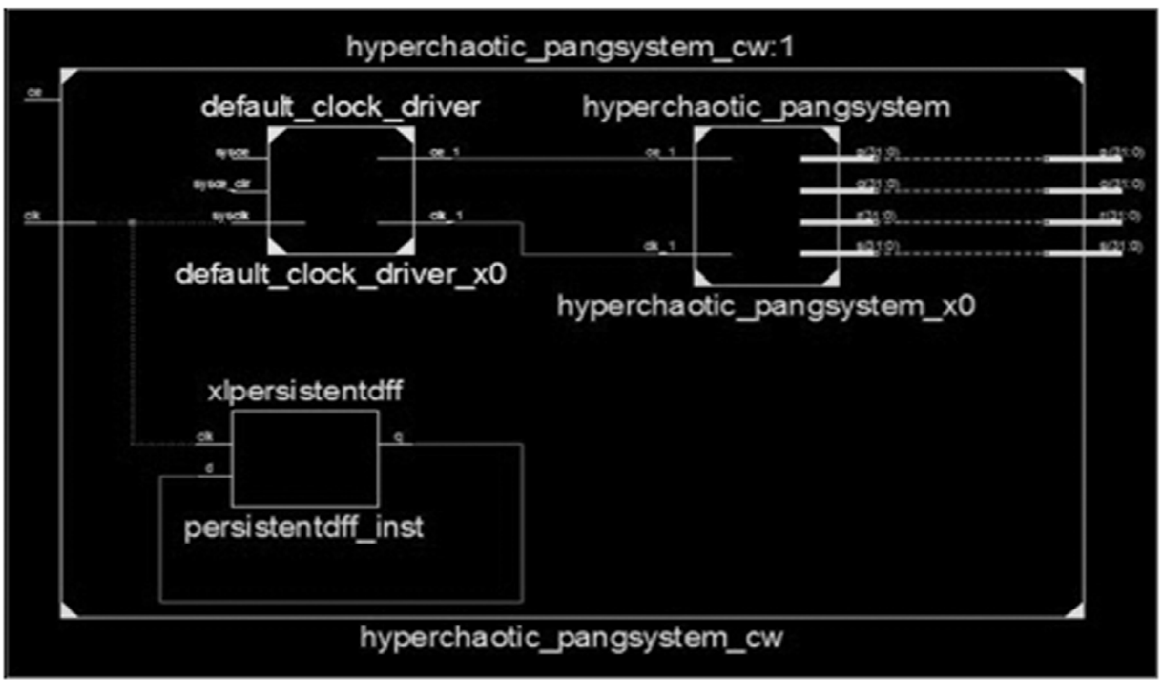


Figure 7: RTL Schematic of Pang Hyperchaotic system

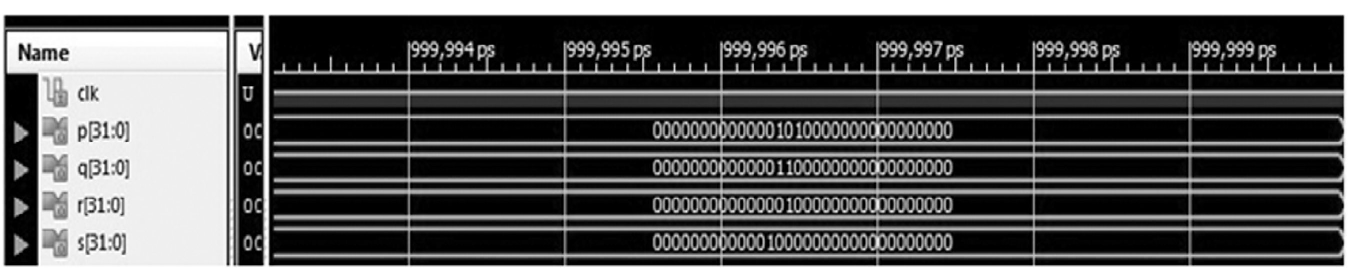


Figure 8: ISim simulation results of VHDL code for Pang Hyperchaotic system

4. DESIGN OF ACTIVE CONTROLLER FOR THE SYNCHRONIZATION OF NON IDENTICAL HYPERCHAOTIC SYSTEM

In this section, based on the active control theory, the complete synchronization between the simplified Lorentz and Pang hyperchaotic system is achieved. In this synchronization methodology, the simplified Lorentz system (1) is considered as a Master system and the Pang system (2) is considered as a Slave system.

The controlled slave Pang system is given by,

$$\begin{aligned} \dot{p} &= \alpha(q-p)+u_1 \\ \dot{q} &= \gamma q - pr + s + u_2 \\ \dot{r} &= -\beta r + pq + u_3 \\ \dot{s} &= -\sigma(p+q)+u_4 \end{aligned} \tag{3}$$

Here u_1, u_2, u_3, u_4, are the nonlinear active controllers to be designed. The complete synchronization error dynamics are defined as, $\dot{e}_1 = \dot{p}-\dot{x}$, $\dot{e}_2 = \dot{q}-\dot{y}$, $\dot{e}_3 = \dot{r}-\dot{z}$ and $\dot{e}_4 = \dot{s}-\dot{w}$.

The nonlinear active controllers can be derived as,

$$\begin{aligned} u_1 &= -\alpha(q-p)+(y-x)-k_1e_1 \\ u_2 &= -\gamma q + pr - s - (xz-w) - k_2e_2 \\ u_3 &= \beta r - pq + (xy-a) - k_3e_3 \\ u_4 &= \sigma(p+q) - by - k_4e_4 \end{aligned} \tag{4}$$

Here k_1, k_2, k_3 and k_4, are the real positive constatnts. Consider the Lyapunov function as,

$$\begin{aligned} V(e) &= \frac{1}{2}e^Te = e_1\dot{e}_1 + e_2\dot{e}_2 + e_3\dot{e}_3 + e_4\dot{e}_4 \\ \dot{V}(e) &= -(k_1e_1^2 + k_2e_2^2 + k_3e_3^2 + k_4e_4^2) \end{aligned}$$

Thus, by Lyapunov stability theory, it is immediate that the synchronization errors e_1, e_2, e_3 and e_4 decay to zero exponentially with time.

5. FPGA IMPLEMENTATION OF SYNCHRONIZED NON IDENTICAL HYPERCHAOTIC SYSTEMS

In this section, nonlinear active controllers (4) and the synchronized hyperchaotic systems are implemented in FPGA. The positive constants are taken as $k_i = 2$, where $i = 1, 2, 3, 4$.

The implementation of active controller signals (4) is shown in Figure 9. The implementation of synchronized Hyperchaotic system is shown in the Figure 10. The master subsystem contains the block diagram of simplified Lorentz Hyperchaotic system (1), the slave subsystem contains the block diagram of slave Pang hyperchaotic system (3) and the control commands subsystem contains the Figure 9.

The initial conditions for the state variables of master system can be chosen $\{x(0), y(0), z(0), w(0)\} = \{2, 4, 1, 3\}$and the initial conditions for the state variables of slave system can be chosen as $\{p(0), q(0), r(0), s(0)\} = \{5, 6, 2, 8\}$. Hence the initial values for error signals are $\{e_1(0), e_2(0), e_3(0), e_4(0)\} = \{3, 10, 1, 11\}$. The state variables of synchronized master and slave hyperchaotic system and the error signals for complete synchronization are shown in Figure 11.

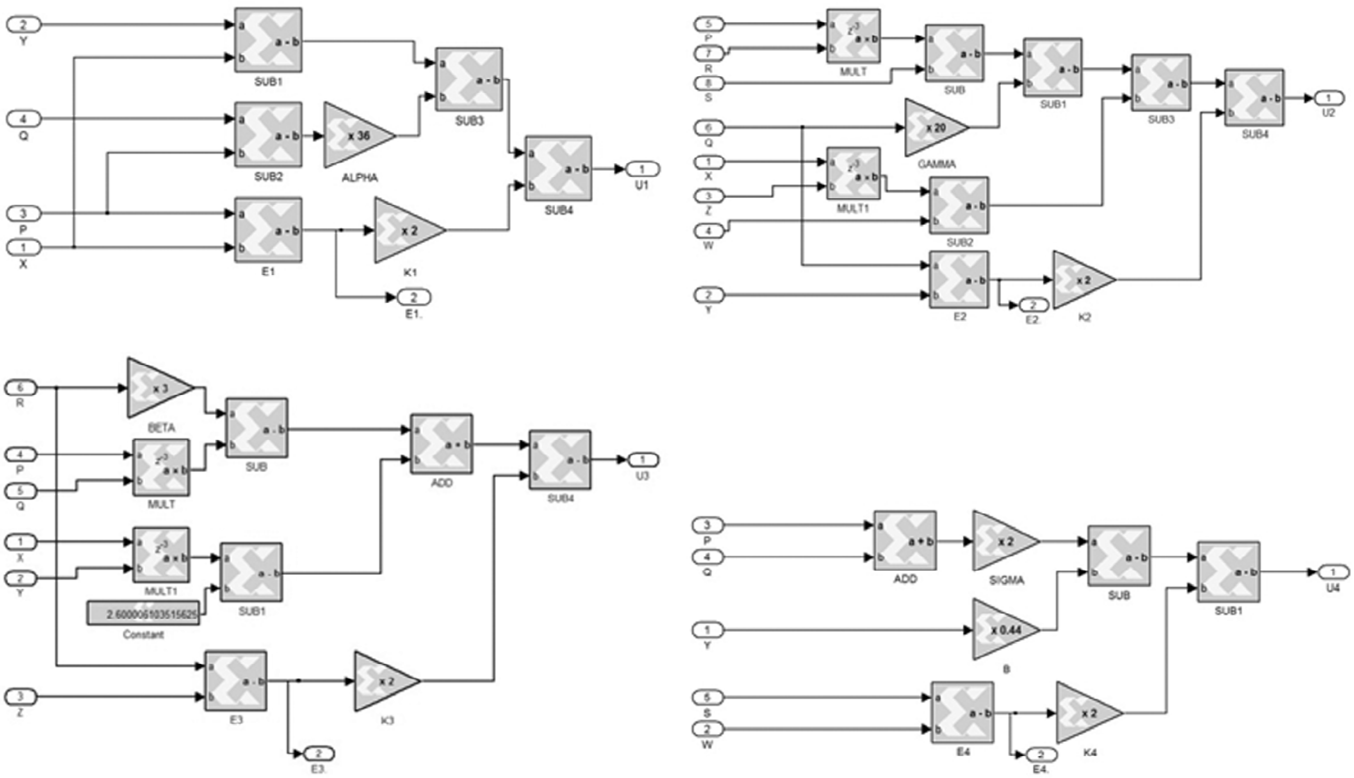


Figure 9: Implementation of error signals (e_1, e_2, e_3, e_4) and active controllers (u_1, u_2, u_3, u_4)

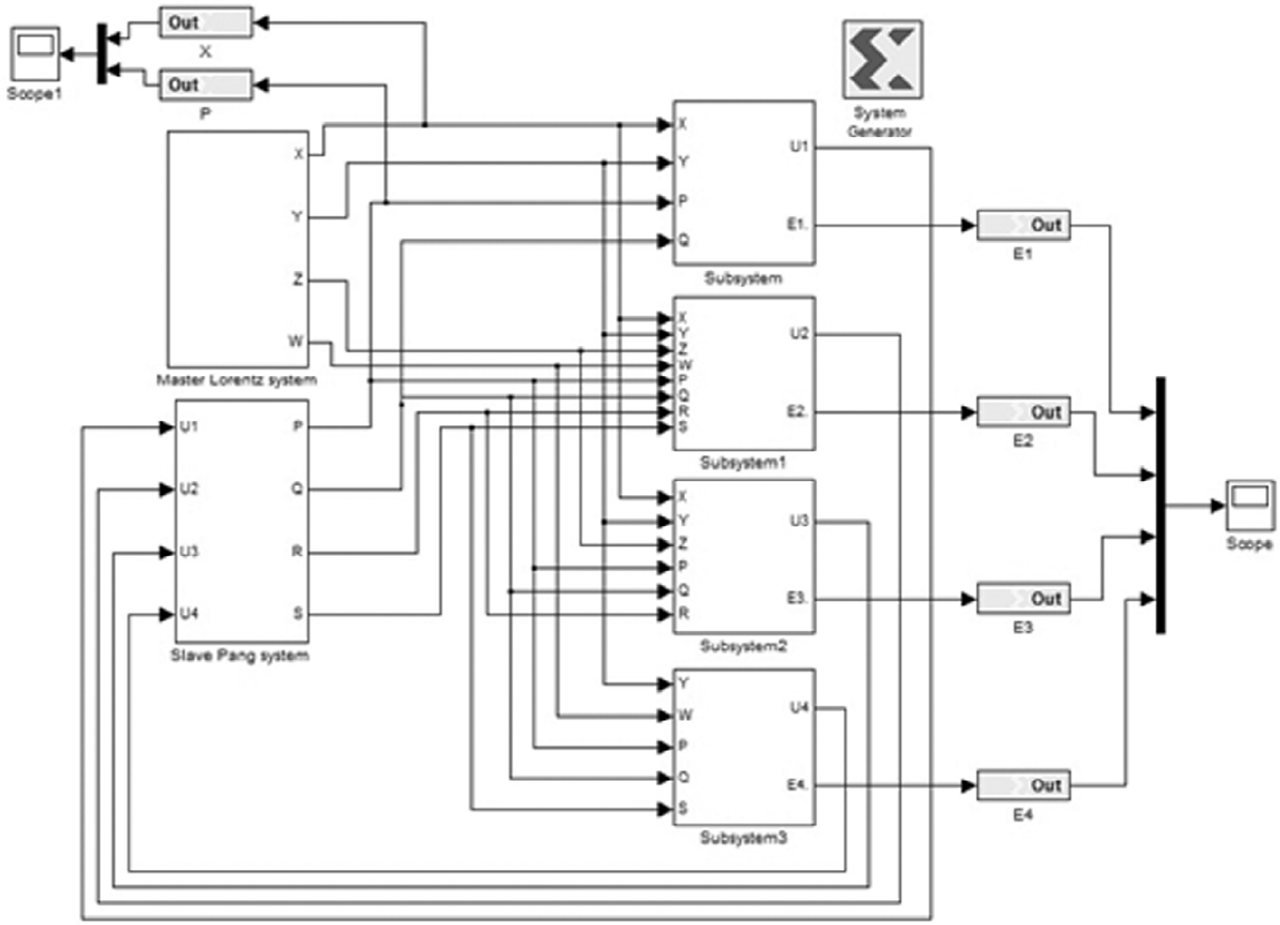
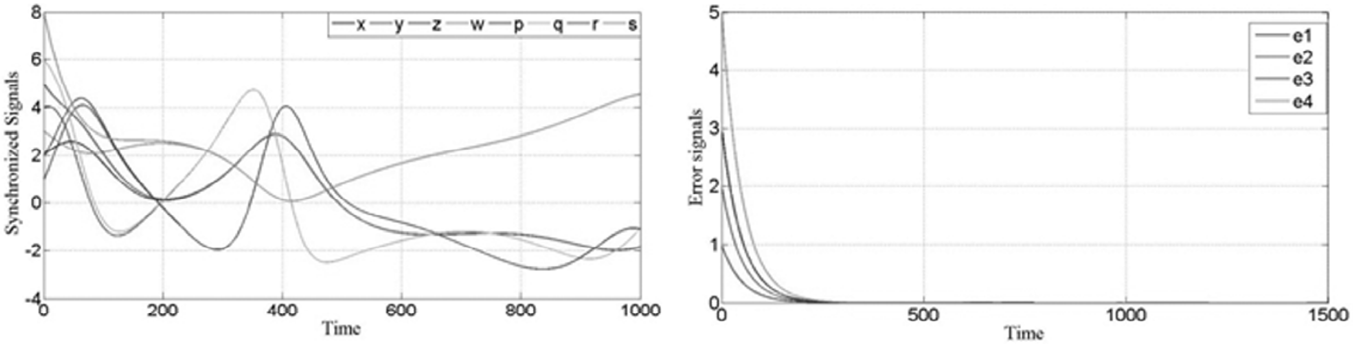


Figure 10: Implementation of complete synchronization of simplified Lorentz and Pang hyperchaotic system in XSG technology



(a) State variables **(b) Error signals**

Figure 11: State variables and error signals for complete synchronization of simplified Lorentz and Pang hyperchaotic system

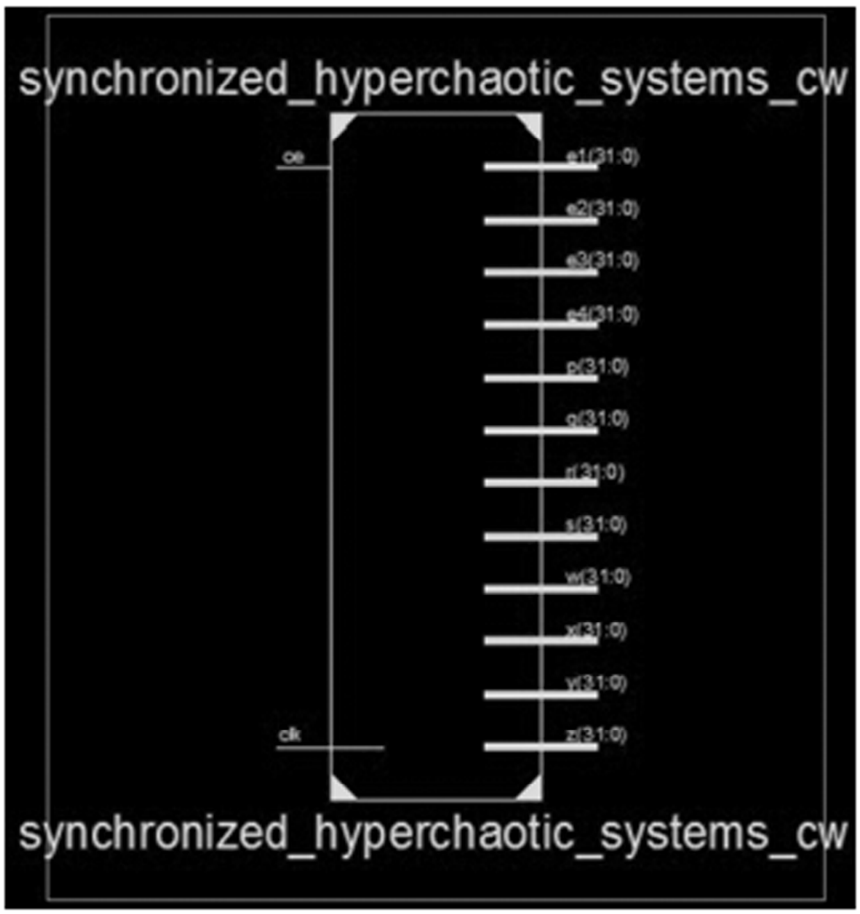


Figure 12: RTL Schematic of synchronized Simplified Lorentz and Pang hyperchaotic system

The implemented structure of the synchronized simplified Lorentz hyperchaotic system and Pang hyperchaotic system in Xilinx ISE into Virtex6 xc6vsx315t-3ff1156 is shown in the Figure 12. The result of VHDL code simulation using Xilinx Isim simulator is shown in the Figure 13 which presents a portion of the waveform of synchronized signals. The signal has the numerical value 2, and has the numerical value 5, therefore has the value 3. The signal has the numerical value 4, and has the numerical value 6, therefore has the value 2. The signal has the numerical value 1, and has the numerical value 2, therefore has the value 1. The signal has the numerical value 3, and has the numerical value 8, therefore has the value 5.

The VHDL code is generated from the system generator design (Figure 10) and is used to configure the FPGA Virtex6 xc6vsx315t-3ff1156. Figure 14 shows the oscilloscope output for the synchronized non identical hyperchaotic systems.

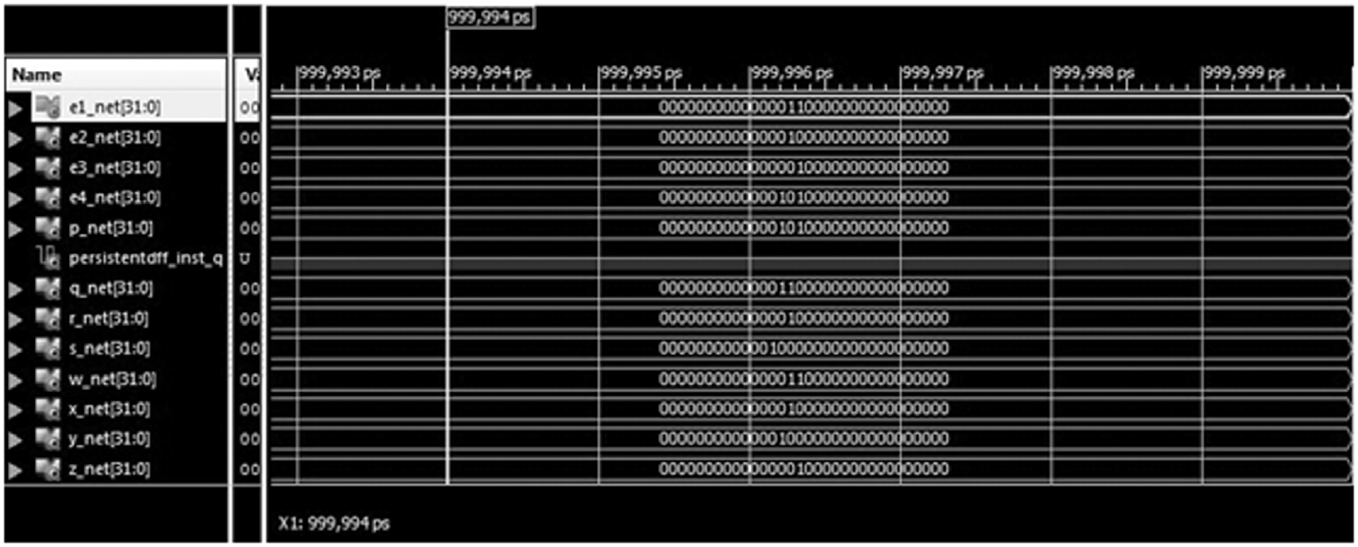


Figure 13: ISim simulation results for complete synchronization of simplified Lorentz and Pang Hyperchaotic system

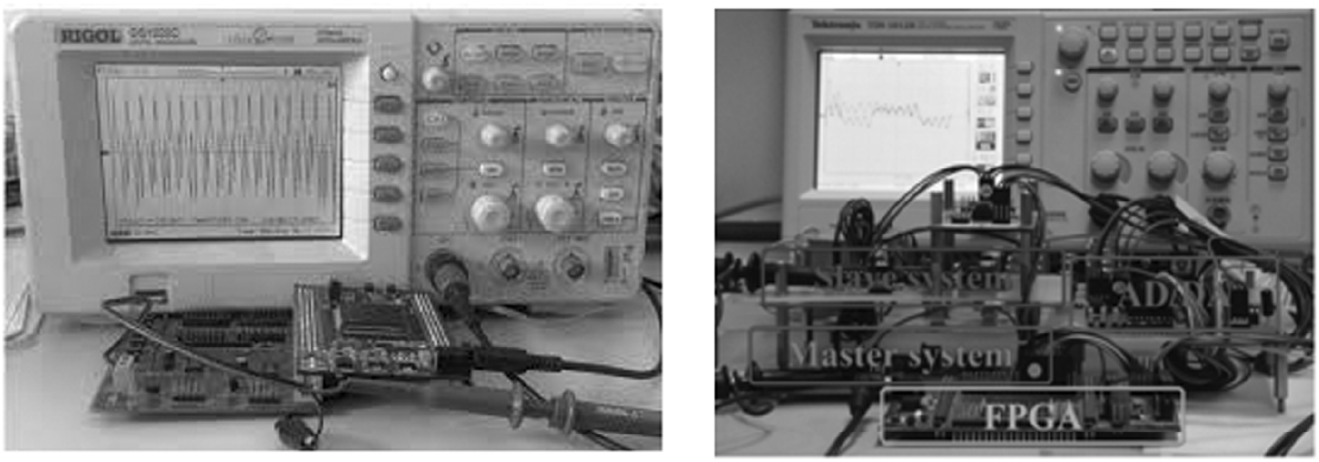


Figure 14: Oscilloscope outputs for the synchronized non identical hyperchaotic systems

5. CONCLUSION

In this paper, FPGA implementation of complete synchronization methodology for non identical hyperchaotic system is proposed. The proposed method has been derived according to Lyapunov stability theory. Since the Lyapunov exponents are not required for these calculations, the active control method is efficient for the complete synchronization of non identical hyperchaotic systems. The simplified Lorentz hyperchaotic systems, Pang hyperchaotic system, active controller, and the synchronized non identical hyperchaotic systems are implemented in FPGA Vertex 6. The simulations results and experimental results are indicating that the proposed methodology is very effective and convenient to synchronize the non identical hyperchaotic systems.

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