ADBA Chaos and Fractals
Cutting-Edge Scientific Solutions

e-ISSN: 3023-8951
RESEARCH ARTICLE
Vol.1 / No.1 / 2024 / pp.38-41
https://doi.org/10.69882/adba.chf.2024075

Digital Implementation of Chaotic Systems Using Nvidia Jetson AGX Orin and Custom DAC Converter

Berkay Emin [*,1] **and Mustafa Yaz** [α,2]

[*]Department of Electronics and Automation, Osmancık Omer Derindere Vocational College, Hitit University, Corum, 19500, Turkiye, [α]Department of Electrical and Electronics Engineering,Faculty of Engineering and Architecture, Yozgat Bozok University, 66900 Yozgat, Turkiye.

ABSTRACT Digital implementation of chaotic systems has many advantages. Chaotic systems realized on digital platforms offer higher flexibility and computational accuracy compared to traditional analog systems. This flexibility and accuracy are of great importance for engineering applications. Furthermore, digital solutions are usually more cost-effective, which is a great economic advantage. In this study, Nvidia Jetson AGX Orin board and 16-bit converter board are used for digital realization of chaotic systems. The Nvidia Jetson AGX Orin is a platform that stands out with its high processing power and energy efficiency. The 16-bit converter card stands out with its sensitive data processing capacity. Thanks to this technological infrastructure, chaotic system equations can be successfully solved in a digital environment and more advanced, flexible, reliable and cost-effective solutions are obtained. These solutions provide significant advantages in various applications in engineering. In particular, the use of digital chaotic systems in areas such as modeling, simulation and control of complex systems offers more efficient and effective results than traditional methods. Digital platforms also facilitate parametric investigations and optimization processes of chaotic systems, enabling more in-depth analysis.

KEYWORDS
Chaotic system
Nvidia Jetson AGX Orin
Digital analog converter
Oscilloscope

INTRODUCTION

With technological advancements, the implementation of chaotic systems in digital environments is becoming increasingly important. Powerful microcontrollers, such as the Nvidia Jetson AGX Orin board, provide an ideal platform for performing complex computations of these systems at high speed and efficiency. The use of 16-bit based converter boards, in particular, enables more precise and detailed results. Such advancements enhance the real-time application of chaotic systems, facilitating the creation of more secure communication systems.

In this context, Wang et al. have implemented a fractional-order Chua circuit system using a microcontroller-based circuit. In their study, the dynamic properties of the fractional-order Chua circuit system were calculated using the ATmega328p microcontroller on the Arduino UNO platform, and these calculations were transferred to a computer via USB (Wang *et al.* 2021).

Méndez-Ramírez *et al.* (2021) introduced a novel hyperchaotic system (NHS) derived from the Méndez-Arellano-Cruz-Martínez (MACM) 3D chaotic system. To achieve real-time simulation and execution of the NHS's digital version (DV), they utilized the Digital Signal Processing (DSP) capabilities of a 16-bit dsPIC microcontroller in conjunction with two external dual digital-to-analog converters (DACs). This configuration facilitates the conversion of digitally processed data into analog signals, making them applicable for real-time scenarios.

In their work, Fan and Ding developed a microcontroller-based platform including components such as the TMS320F28335 DSP chip and 16-bit DAC to demonstrate the hardware implementation and geometric control of the polynomial chaotic map (Fan and Ding 2023). In the study Dong and Yang (2024), the dynamics, periodic trajectories and DSP (Digital Signal Processing) implementation of a new memristor-based 4D hyperchaotic system were performed. A D/A dual-channel converter (DAC8552) was used to convert the digital array into analog array. Finally, the analog signal was input to an oscilloscope to obtain an image of the hidden hyperchaotic attractor. In their study, Köse and Mühürcü (2017) focused on the realization of a digital chaotic oscillator using a low-cost microcontroller and chose to use a cost-effective microcontroller instead of many circuit elements to generate chaos signals. In this study, the algorithm for generating chaotic signals is realized using a PIC18F452 microcontroller and a DAC7611. The results are visualized on the oscilloscope screen in the form of 1D and 2D graphs. This method provides a cost-effective solution with less hardware requirements and facilitates the generation of chaotic signals. Chiu *et al.* (2019) conducted a study on designing

Manuscript received: 28 July 2024,
Revised: 30 July 2024,
Accepted: 30 July 2024.

[1]berkayemin@hitit.edu.tr (**Corresponding author**)
[2]mustafa.yaz@bozok.edu.tr

and implementing a jerk circuit through a hybrid analog-digital approach. This involved using a mix of analog components, such as operational amplifiers configured as integrators and various passive elements, alongside digital components, including microcontrollers and DAC/ADC boards.

The experimental findings demonstrate that the proposed hybrid circuit effectively replicates the dynamics of the jerk system.The implementation of chaotic systems in digital environments offers significant advantages across various application areas. For instance, chaotic encryption methods used for secure data transmission protect data from unauthorized access. These methods leverage the dynamic and unpredictable nature of chaotic systems, making it extremely difficult to break encryption keys. In this context, the security advantages provided by chaotic systems are particularly important in military and financial communications. The literature includes designs of chaos-based encryption and random number generators using embedded systems.

Murillo-Escobar *et al.* (2023) proposed a chaos-based cryptographic algorithm utilizing the Badola map to ensure the confidentiality of biomedical signals, such as ECG, in telemedicine applications. They implemented this algorithm in an embedded system based on a low-cost 12-bit microcontroller. The study demonstrates that the proposed chaotic cryptographic algorithm is robust against common attacks and can be effectively used in secure, low-cost embedded systems for telemedicine applications. Emin and Musayev (2023) developed an RGB image encryption algorithm utilizing Lorenz-Rossler chaotic systems for the Nvidia Jetson Nano and Xilinx PYNQ Z1 embedded systems. Their results indicate that the Nvidia Jetson Nano board performs encryption and decryption more rapidly than the Xilinx PYNQ Z1 board.

Murillo-Escobar *et al.* (2024) introduced two novel pseudorandom number generators (PRNGs) based on newly developed hyperchaotic maps. These PRNGs were initially implemented on the Renesas RA4M1 32-bit microcontroller. Pande and Zambreno introduced a new chaotic stream cipher derived from a modified logistic map, designed for real-time applications. They subsequently implemented this cipher in hardware on a Xilinx Virtex6 FPGA. The proposed approach is well-suited for embedded devices that have strict limitations on power consumption, hardware resources, and real-time performance (Pande and Zambreno 2013).

Charalampidis *et al.* (2024) proposed a real-time chaos-based speech encryption scheme based on STM32 microcontroller. They proved the effectiveness of the encryption scheme with various tests. Janakiraman *et al.* (2018) developed a chaos-based image encryption algorithm featuring lightweight design, which was optimized for a 32-bit microcontroller. The performance analysis reveals that this algorithm is appropriate for real-time embedded systems, offering reduced memory usage and improved efficiency.

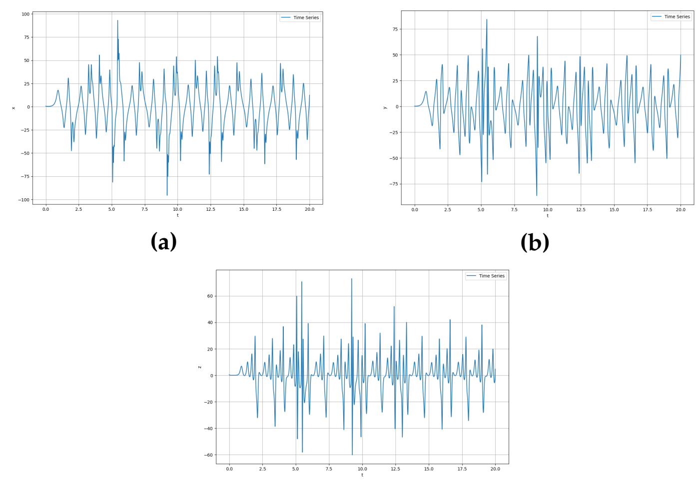
The organization of this paper is as follows: Section 2 presents the mathematical framework of the Four-Wing System introduced by Khaled *et al.* (2024), along with the simulation results for time series and phase portrait. Section 3 focuses on capturing the time series and phase portrait of the Four-Wing System with an oscilloscope, employing the Nvidia Jetson AGX Orin and a DAC-based converter board. The paper concludes with a summary of the findings in the final section.

MATHEMATICAL MODEL OF FOUR-WING SYSTEM

The formula for the Four-Wing System proposed is given in Equation 1 (Khaled *et al.* 2024).

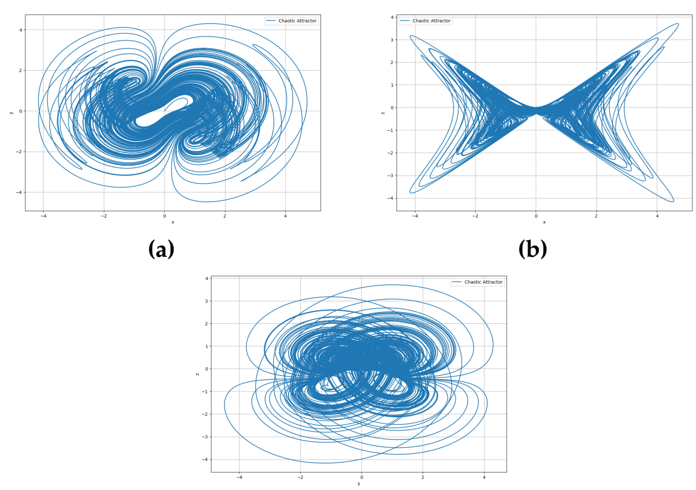
$$\begin{aligned} \dot{x} &= a(y-x) + yz \\ \dot{y} &= bx + cy - xz \\ \dot{z} &= -dz + xy + 1 \end{aligned} \tag{1}$$

where x, y and z are state variables and a, b, c and d are control parameters. System 1 exhibits chaotic behavior for $[x_0, y_0, z_0] = [0.5, 0.2, 0.5]$ and $a = 10$, $b = -5$, $c = 10$ and $d = 30$. The x, y and z time series of the system are shown in Figure 1. Also, the $x-y, x-z$ and $y-z$ phase portraits are presented in Figure 2



(a) **(b)** **(c)**

Figure 1 Time series of the Four-Wing System (a) x-t; (b) y-t; (c) z-t time series.



(a) **(b)** **(c)**

Figure 2 Phase portraits of the Four-Wing System (a)x-y; (b)x-z; (c)y-z phase portrait.

ELECTRONIC CIRCUIT IMPLEMENTATIONS

The high processing power of the Nvidia Jetson AGX Orin board used in this study is of great importance for modeling the complex nature of chaotic systems and performing real-time analysis on these models. In addition, the 16-bit based converter card offers high precision in converting analog signals to digital data, increasing the accuracy of the system and enabling this type of system to have a wider range of applications. The digital implementation of chaotic systems also offers significant advantages in the field of cryptography. The random and unpredictable nature of chaotic signals provides an ideal basis for secure communication systems. Digital platforms facilitate the generation and processing of these signals, contributing to the development of more secure cryptographic algorithms. Furthermore, chaotic implementations on digital systems allow parameters to be changed quickly and easily, enabling systems to adapt to various scenarios. In this chapter, the realization and digital implementation of the Four-Wing System on the Nvidia Jetson AGX Orin board is presented. All simulations and digital implementations of the Four-Wing System were performed using Python language on Nvidia Jetson AGX Orin embedded board and Jupiter programming environment. The block diagram of the application is given in Figure 3.

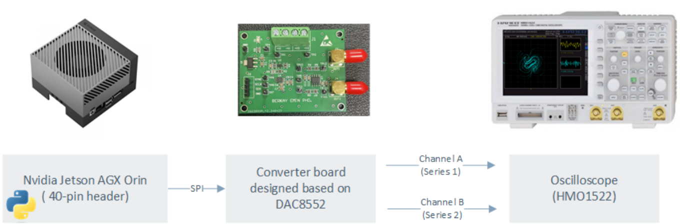
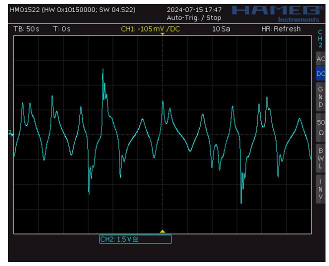


Figure 3 Block diagram of the application

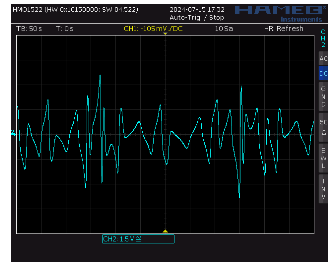
As the Nvidia Jetson AGX Orin embedded board cannot provide analog output, the converter board designed by us was used. This converter board basically consists of the TI 8552 DAC and the OPA2197 opamp. The Nvidia Jetson AGX Orin embedded board was connected to this board via SPI (Serial Peripheral Interface). First, System 1 was analyzed and discretized using the Runge-Kutta 45 method on the Nvidia Jetson AGX Orin embedded board. Given that the converter board can output a maximum of ±5V, the values of the chaotic system were scaled to match this limit. Then, the obtained x, y and z chaotic values were transmitted to the designed converter board. After the board converted the output result, the oscilloscope output was obtained. The oscilloscope images of the time series and phase portraits of System 1 are shown in Figure 4 and Figure 5, respectively.

CONCLUSION

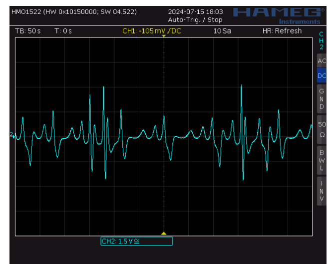
As a result, digital implementations of chaotic systems have great potential for flexibility, reliability and efficiency in engineering. Developed using the Nvidia Jetson AGX Orin board and 16-bit based converter board, these systems offer innovative solutions to complex engineering problems thanks to their high-performance computational capacity. In the future, such systems can be used for real-time signal encryption, random number generation and similar applications, which can further increase the effectiveness of engineering solutions. Furthermore, engineering applications of these chaotic systems can be used in various industries, which can open the door to sectoral innovations.



(a)

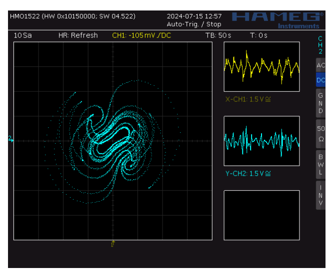


(b)

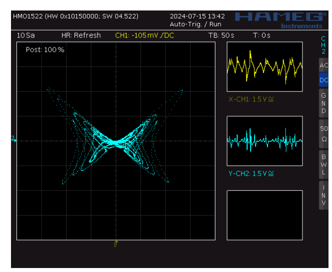


(c)

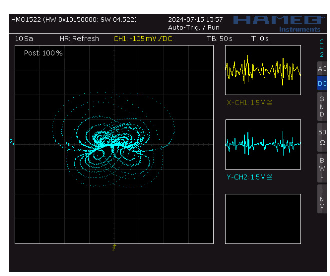
Figure 4 Oscilloscope Images of the time series of the Four-Wing System (a) x-t; (b) y-t; (c) z-t time series.



(a)



(b)



(c)

Figure 5 Oscilloscope Images of the time series of the Four-Wing System (a) x-t; (b) y-t; (c) z-t time series.

Availability of data and material

Not applicable.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical standard

The authors have no relevant financial or non-financial interests to disclose.

LITERATURE CITED

Charalampidis, N., A. Iatropoulos, and C. Volos, 2024 Chaos based speech encryption using microcontroller. Integration **95**: 102128.

Chiu, R., D. López-Mancilla, C. E. Castañeda, O. Orozco-López, E. Villafaña-Rauda, *et al.*, 2019 Design and implementation of a jerk circuit using a hybrid analog–digital system. Chaos, Solitons Fractals **119**: 255–262.

Dong, C. and M. Yang, 2024 A novel 4D memristor-based hyperchaotic system with hidden attractors: Dynamics, periodic orbits analysis, and DSP realization. Chinese Journal of Physics **89**: 930–942.

Emin, B. and Z. Musayev, 2023 Chaos-based Image Encryption in Embedded Systems using Lorenz-Rossler System. Chaos Theory and Applications **5**: 153–159.

Fan, C. and Q. Ding, 2023 Design and geometric control of polynomial chaotic maps with any desired positive Lyapunov exponents. Chaos, Solitons Fractals **169**: 113258.

Janakiraman, S., K. Thenmozhi, J. B. B. Rayappan, and R. Amirtharajan, 2018 Lightweight chaotic image encryption algorithm for real-time embedded system: Implementation and analysis on 32-bit microcontroller. Microprocessors and Microsystems **56**: 1–12.

Khaled, B., R. Moghrabi, A. Sambas, S. Kacar, S. Uzun, *et al.*, 2024 A novel four-wing chaotic system with multiple equilibriums: Dynamical analysis, multistability, circuit simulation and pseudo random number generator (PRNG) based on the voice encryption. International Journal of Data and Network Science **8**: 989–1000.

Köse, E. and A. Mühürcü, 2017 Realization of a digital chaotic oscillator by using a low cost microcontroller. Engineering Review **37**: 341–348.

Méndez-Ramírez, R. D., A. Arellano-Delgado, M. A. Murillo-Escobar, and C. Cruz-Hernández, 2021 A new 4d hyperchaotic system and its analog and digital implementation. Electronics (Switzerland) **10**: 1–18.

Murillo-Escobar, D., C. Cruz-Hernández, R. M. López-Gutiérrez, and M. A. Murillo-Escobar, 2023 Chaotic encryption of real-time ECG signal in embedded system for secure telemedicine. Integration **89**: 261–270.

Murillo-Escobar, D., K. Vega-Pérez, M. A. Murillo-Escobar, A. Arellano-Delgado, and R. M. López-Gutiérrez, 2024 Comparison of two new chaos-based pseudorandom number generators implemented in microcontroller. Integration **96**: 102130.

Pande, A. and J. Zambreno, 2013 A chaotic encryption scheme for real-time embedded systems: Design and implementation. Telecommunication Systems **52**: 551–561.

Wang, J., L. Xiao, K. Rajagopal, A. Akgul, S. Cicek, *et al.*, 2021 Fractional-Order Analysis of Modified Chua's Circuit System with the Smooth Degree of 3 and Its Microcontroller-Based Implementation with Analog Circuit Design.

How to cite this article: Emin, B., and Yaz, M. Digital Implementation of Chaotic Systems Using Nvidia Jetson AGX Orin and Custom DAC Converter.*Chaos and Fractals*, 1(1), 38-41, 2024.