Computer Modelling, Analysis of the Main Information Properties of Memristor and Its Application in Secure Communication System

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Abstract

In this paper, we present equation and system parameters that realize memristive chaotic system. The analysis and computer modelling of the main information properties of memristor are shown. For this, we created programming interface using one of the modern software LabView that allows to generate, analysis and research of the main information properties of memristor, focusing on time series of the three coordinates and phase portraits. The created another programming interface that demonstrates the masking and decrypt of the information are also presented.

Keywords

Memristor, information properties, LabView, security system

1. Introduction

Chaos theory has been established since the 1970's due to its applications in many different engineering research areas, such as robotics [1], electronic circuits of chaotic generators [2-11], information security [12-14], etc. Many chaotic systems are realized using Arduino [15] and FPGA [16-21].

In 1971, Leon Chua suggested the existence of another basic element of the electrochemical system, which realizes the connection between magnetic flux and charge. In 2008, scientists managed to discover a new component. This component is called a memristor, this term was formed as a result of merging the words "memory" and "resistor" (electrical resistance). This term refers to a bipolar device, the electrical resistance of which varies depending on the amount of charge flowing through it. The resistance of the memristor is called the memristor (M), which is defined as the ratio of the change in the magnitude of the magnetic field flux to the change in charge, and its value depends on how long the electric current flows through the memristor, that is, the amount of charge that passed through it.

The main advantage of a memristor is properties that are not stored in the form of a charge. These properties differ from most types of modern semiconductor memory elements. This is the main advantage, because it is not afraid of charge leakage, which is the main evil that everyone wants to get rid of when switching to "nanochips". Another advantage of the memristor is its energy independence. These properties ensure that the memristor is stored at the same time as the existing materials used to make it. The successful production of the memristor by Hewlett Packard (HP) greatly increased the interest of researchers in the memristor. Many scientists began to use the memristor in analog systems and in digital media. Others have used memristors as resistive memory modules and logic programs. The potential of using a memristor in neuromorphic applications has also been studied by many researchers [22-25].

Memristors, first of all, are extremely promising elements of binary non-volatile memory, in which information is recorded by switching electrical resistance between resistive states with low (ON) and high (OFF) resistance. Moreover, their electronic states "adjust" to input signals,

CMIS-2024: Seventh International Workshop on Computer Modeling and Intelligent Systems, May 3, 2024, Zaporizhzhia, Ukraine
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just as living organisms do. This is why memristors can imitate the functioning of biological synapses connecting neurons in the brain. The main function of the latter is to transmit a signal from one neuron to another, and the magnitude of the connection between neurons depends on the relative time of their "firing". It is this mechanism that is responsible for associative learning, that is, the brain's ability to find connections between different events, so the memristor can be considered a prototype of an "electronic synapse".

Research in the field of artificial intelligence, and more specifically on the creation of an artificial brain based on memristors, is also being conducted at Michigan State University under the leadership of Wei Lu. Here, a memristor model was built based on a layer of a mixture of silver and silicon and tungsten electrodes, and in the near future the scientists plan to create large circuits consisting of thousands of such elements.

The already studied properties of memristors allow us to say that on their basis it is possible to create computers of a fundamentally new architecture, with performance significantly exceeding semiconductor ones. Modern computers are built on the von Neumann architecture: both data and programs are stored in the machine's memory in binary code, with the computing module separated from the storage devices, and the programs executed sequentially, one after the other. Progressive in the middle of the last century, such an architecture today no longer meets the requirements for computer technology: programs have become much more complex, and the volume of processed data has grown by orders of magnitude, if not tens of orders of magnitude.

A computer based on memristors could be a significant step forward, since it is capable of simulating the functioning of the human brain, which does not have any single center for collecting and processing information. Each block receives, processes and transmits its own data arrays to other blocks, muscles, and sensory organs, which are insignificant compared to the entire volume of incoming information. According to recent estimates, to build a model of the human cerebral cortex from modern computer components, you will need at least 150,000 processors and 144 TB of RAM alone, and we are not even talking about the intelligence of a baby.

In a memristor computer, many modules operate in parallel and independently of each other, and the ability to store and operate an unlimited set of values from 0 to 1 means that executable programs are not limited to binary code. Moreover, individual computer hardware components - processors, video chips, memory and hard drives - will become unnecessary in principle; the machine will be an architecturally homogeneous device where all data will be simultaneously stored and all operations with it will be carried out. For an upgrade, it will be enough to install additional memristor modules, and for repairs, replace the failed ones.

The memristor computer will not need to be "booted": immediately after turning it on, it will be ready to continue working, and from the very point where it was interrupted. Compared to modern technology, the energy consumption of memristor machines will be negligible, and the computing power will be simply gigantic.

Considering that there is literally one step left before the mass production of memristors, it is very possible that a memristor computer will become an intermediate step on the path to a quantum computer.

2. Computer modelling of the main information properties of memristor

The common thread that binds these four elements together as the four basic elements of circuit theory is the fact that the characteristics of these elements relate the four variables in electrical engineering (voltage, current, flux and charge) intimately. Fig. 1 shows this relationship graphically.

Nonlinear behavior of memristive information properties is described by next equation system (1):

$$\begin{cases} \dot{x} = \frac{y}{C}; \\ \dot{y} = \frac{-1}{L}[x + \beta(z^2 - 1)y]; \\ \dot{z} = -y - \alpha z + yz. \end{cases} \tag{1}$$

A chaotic time series is a sequence of data that exhibits chaotic behavior over time when plotted. A characteristic of chaotic signals is that they are sensitive to initial conditions. This means that a small change in the initial conditions can cause the results to look very different over time. Chakotic signals often look chaotic and unpredictable. They look like random noise, but they have a underlying deterministic dynamic.

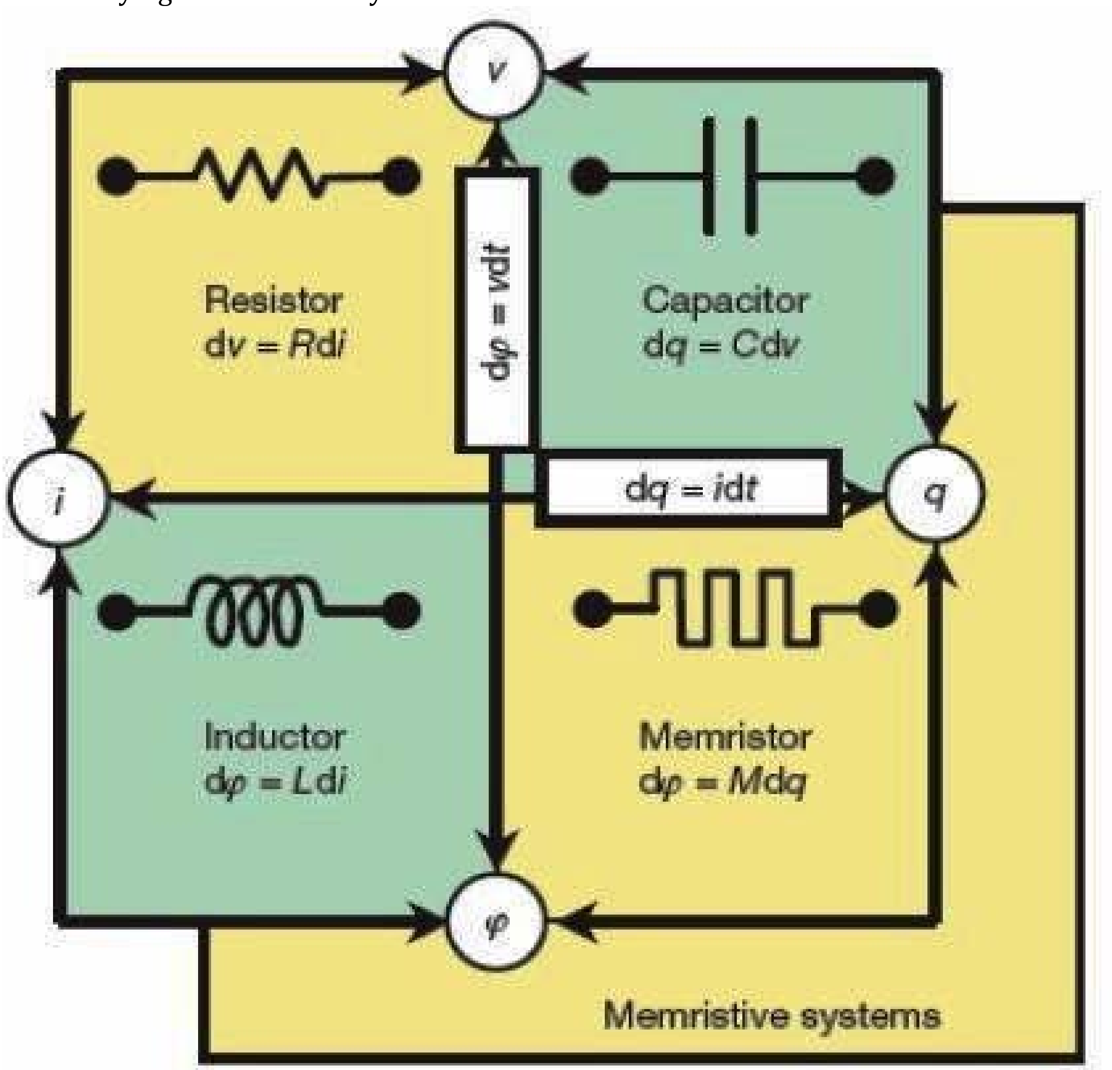

Figure 1: The four basic circuit elements

The logistic map, the Henon map, the Lorenz and Rossler systems are examples of chaotic signals [26-30]. These chaotic signals used in different physical systems and mathematical models, such as economics, radioengineering, physics, mathematics [31-43].

Time series for X, Y and Z coordinates are shown in Fig. 2. The parameter values are: $C = 1$, $L = 3$, $\alpha = 0.6$, $\beta = 1.5$, $dt = 0.01$, number of iterations $N = 10000$. For modelling was used modern software environment LabView.

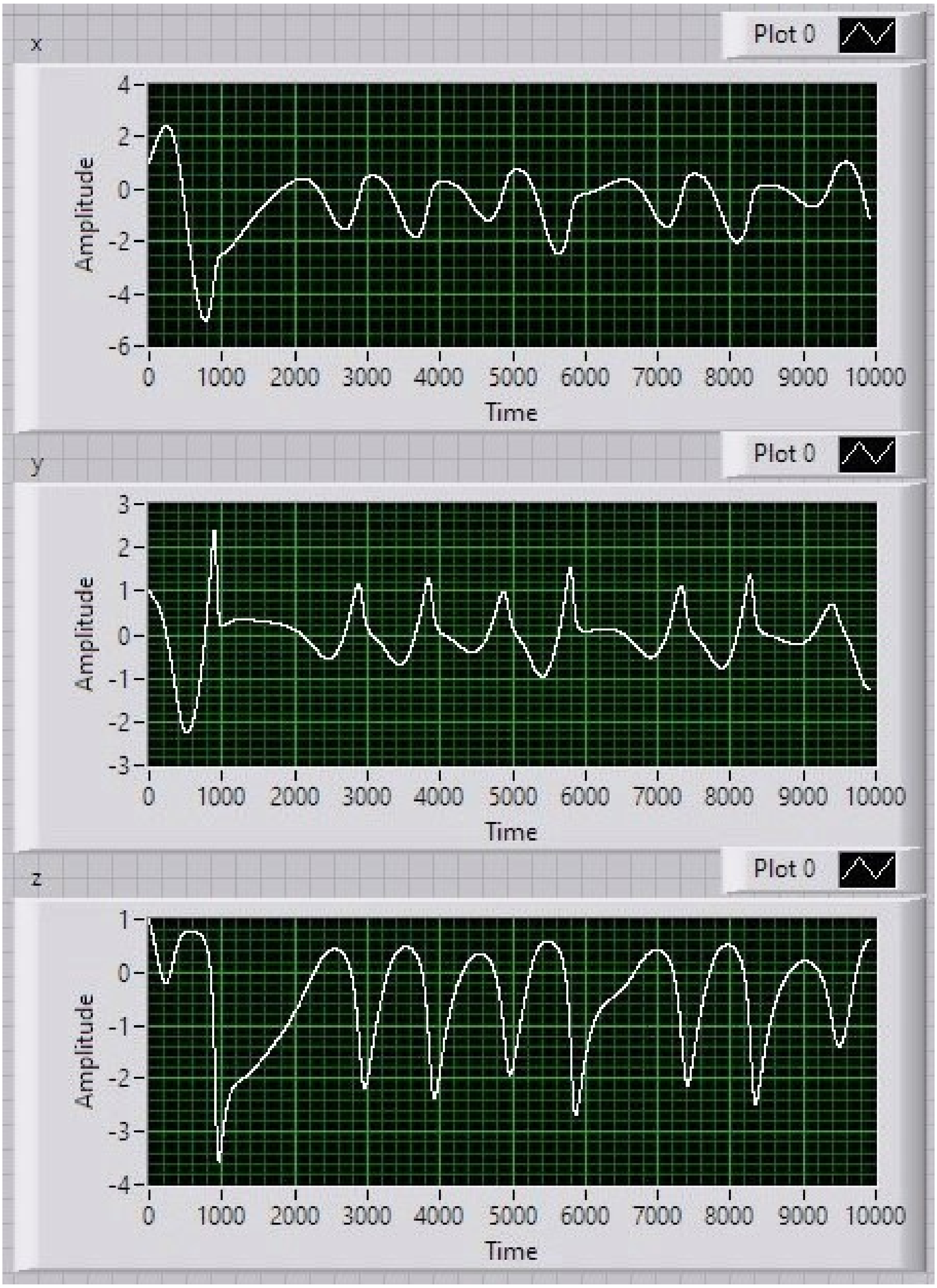

Figure 2: Time series for X, Y and Z coordinates

Until recently, specialists, when solving problems in their own subject area, were forced to resort to the help of professional programmers, who, as a rule, were not knowledgeable in this area. Such intermediation most often increased material and time costs, and most importantly, reduced the quality of research and development. Even the use of specialized software only partially solved this problem. The emergence of the latest generation of software products with very user-friendly interfaces, adapted to the mentality and professional skills of specialists, has made it possible for specialists to use them directly, without resorting to the help of intermediaries. These new software products include LabVIEW, which has a very convenient user interface and powerful graphical programming tools. With each subsequent version of LabVIEW, the level of intellectualization of the user interface and ease of use increases.

LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language created by National Instruments. The purpose of this language is to automate the use of computational and measuring laboratory equipment.

For more than 35 years, engineers and scientists have used NI LabVIEW to develop measurement systems, test benches, and control systems. LabVIEW is based on the graphical programming language G. In addition to being programmable, LabVIEW provides a wide range of tools and libraries, from interactive wizards and user interfaces to built-in compilers, linkers, and debugging tools.

There are two main differences between LabVIEW and other programming languages. First, LabVIEW implements the concept of graphical programming, so the source code is a block diagram (icons of language elements connected together), which is then compiled into machine code. Despite this approach, LabVIEW uses the same programming constructs and techniques as other languages: data types, loops, variables, recursion, event handling, and object-oriented programming.

The second distinctive feature of LabVIEW is its support for executing code written in the G language in a data stream mode (stream programming), while traditional text-based languages (for example, C and C++) provide code execution as a sequence of commands. Stream programming languages (such as G, Agilent VEE, Microsoft Visual Programming Language and Apple Quartz Composer) are based on the concept of data flow, which determines the sequence of execution of the functional units of the program.

At first it may seem that the difference between this approach and the traditional one is not significant, but in practice it turns out differently. Namely, stream programming in the LabVIEW environment allows the developer to fully focus on the data and how to process it. Program nodes - functions, loops and other language constructs - receive data through inputs, process them and output data using outputs. As soon as the parameter values arrive at each of the input terminals of the node, the node code is executed (processing of the incoming data), after which the values of the output parameters are available at the output terminals of the node for their further transmission to other nodes according to the logic of the data flow. Accordingly, of two sequentially connected nodes, the second one can be executed only after receiving data from the previous one.

Because the G language concept is easy to understand, LabVIEW provides equally user-friendly and intuitive development environment tools. For example, unique debugging tools allow you to visually display the process of data propagation along wires, as well as display the corresponding values at the inputs and outputs of code nodes (we are talking about execution animation).

LabVIEW's graphical language and flow programming concept allows you to solve problems more conveniently and efficiently than traditional text-based languages. The key features of LabVIEW programming—namely, intuitive, graphical code and data-driven execution—make programming more thought-like than other languages. Despite the high level of code abstraction, the performance of programs written in LabVIEW remains comparable to languages like C, thanks to the built-in code compiler.

Another information property of memristor are phase portraits (Fig. 3).

For qualitative analysis of nonlinear circuits, the phase space method is used. The current values of the state variables of the analyzed circuit are plotted on its coordinate axes. Their changes in time correspond to certain curves—phase trajectories—in the space of state variables. The set of all phase trajectories—the phase portrait of the circuit—represents a comprehensive description of all its possible modes.

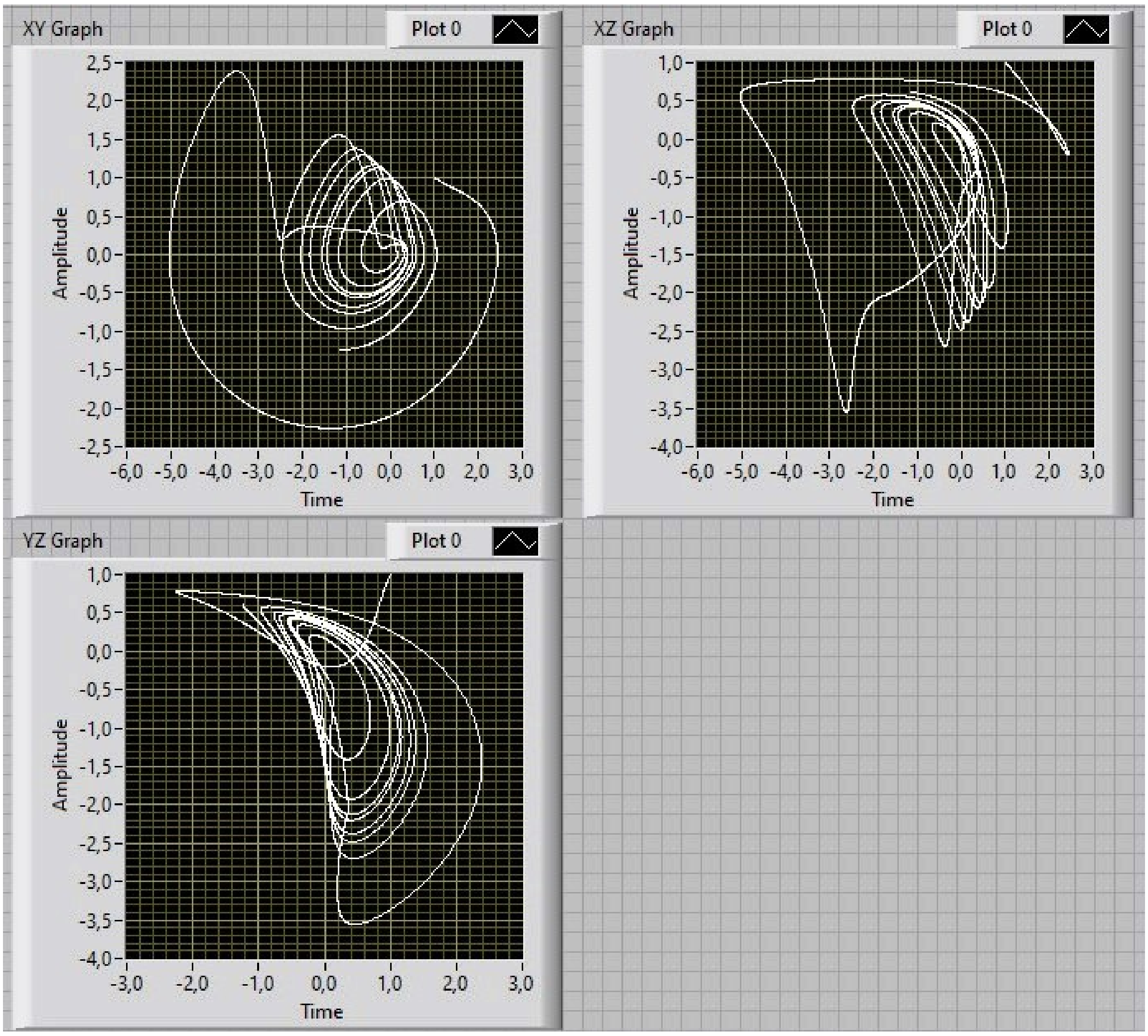

Figure 3: Phase portraits in XY, XZ and YZ projections

3. Masking and decryption of the information using memristor

Protecting information from unauthorized access is one of the most pressing tasks in telecommunications. Often in telecommunication systems, we deal with digital signals as an information carrier, for which there are already effective protection methods based on cryptography algorithms. In the case of analog signals, other methods of information protection are required, one of which is the masking method. The essence of this method is that it is necessary to find a specific signal source that has the same spectral properties as the protected information signal. Accordingly, if such a signal is mixed with an information signal, the resulting signal turns out to be uninformative, and as a result, the information signal turns out to be protected.

The last decade has been known for extreme interest in the possibility of using dynamic chaos for data encryption. At a conceptual level, there is a peculiar relationship between chaotic systems and cryptographic systems. Therefore, in nonlinear dynamics, and in cryptography, nonlinear transformation of information materializes. Such a transformation is deterministic (for example, performed by a computer), on the other hand, it must be unpredictable for an external observer. Therefore, the word “deterministic chaos” is quite “suitable” for cryptography.

The block scheme demonstrates process of transmitting and receiving information using chaotic signal for masking and decryption (Fig. 4). In this case, the transmitter and the receiver systems are identical.

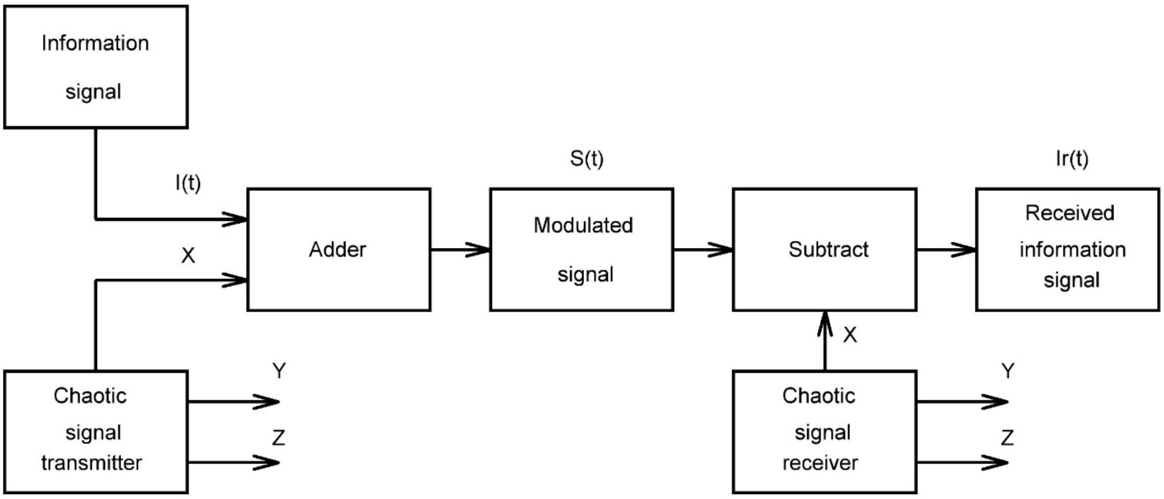

Figure 4: The block scheme for transmitting and receiving information using chaotic signal for masking and decryption

The masking of the information based on nonlinear properties is provided by blending information with the chaotic signal that was generated of the different coordinates. As an information, there was used a sinusoidal signal with amplitude of 5 *V* and system parameters $\alpha = 0.6$, $\beta = 1.5$, $C = 1$, $L = 3$, $dt = 0.01$, number of iterations $N = 10000$, dynamic variables $x = y = 1$. Dynamic variables and system parameters are the keys for the masking information.

Algorithm for the decryption has opposite effect.

The program interface, which demonstrates the masking and decrypt of the information based on a properties of memristor system (1) is presented in Fig. 5.

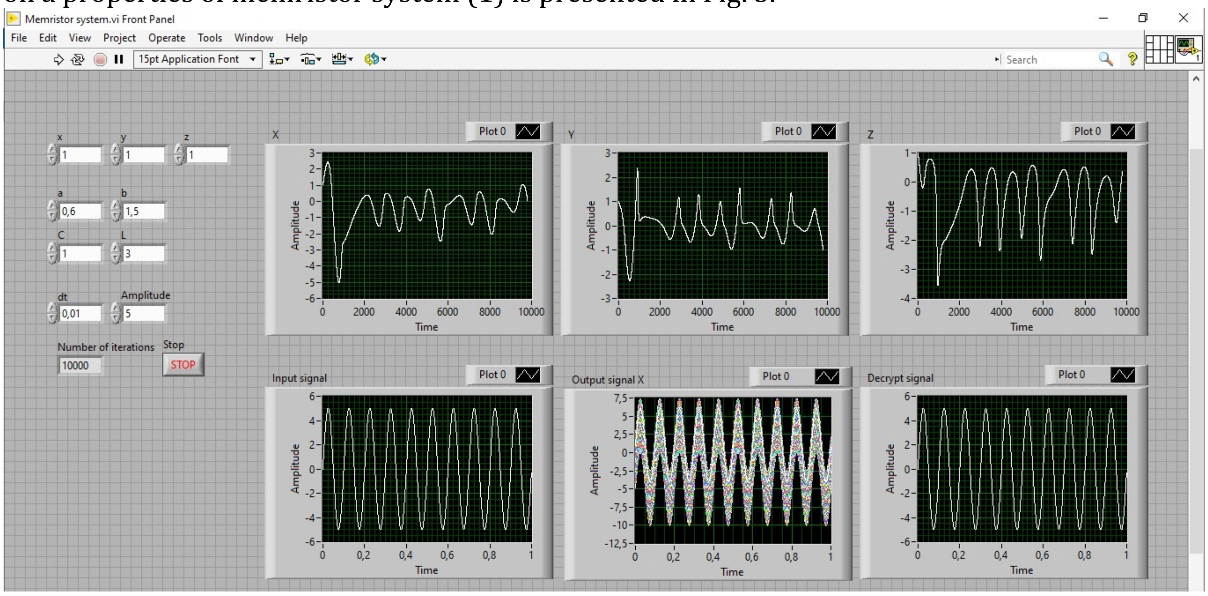

Figure 5: Software interface shows masking and decryption of the information

4. Discussion

A memristor is a two-contact device, which means that a memristor can be integrated into multilayer matrices of mutually perpendicular metal nanowires. Its architecture is significantly more compact compared to modern semiconductor silicon processors, besides, the logic of controlling such a matrix of intersecting nanowires is significantly simpler. The fundamental and main difference between a memristor and most types of modern semiconductor memory is that it does not retain its properties in the form of a charge. A memristor is not characterized by charge leakage during recording, thus it can be said that it is completely non-volatile. It is implied that the information recorded in the memristor can store digital information for several tens of years. The duration of information storage depends on the material of the memristor.

Compared to these digital memory stores, the memristor has a much longer lifetime. With the help of memristor technology, it is possible to design a new generation of computer equipment that will surpass computers in such parameters as: speed, energy efficiency, the ability to process large streams and volumes of information. Memristor technology is also widely used in robotics. A memristor can be used as a bipolar key, a memory element, or a component of a logic element.

5. Conclusions

There was used one of the modern software LabView (LabView-2020 (64-bit version for Windows) for the analysis and modelling of the main information properties of memristor. Equation and system parameters that realized memristive chaotic system are shown. The main information properties of memristor such as a time series of the three chaotic X, Y and Z coordinates and phase portraits in XY, XZ and YZ projections are presented. Masking and decrypting of the information are presented using programming interface. Memristor that generate nonlinear oscillations can be used as one of the main parts in modern communication systems for security of information.

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