POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://dergipark.org.tr/politeknik

EMERGING SOURCES CITATION INDEX

Implementation of a real time analog secure image communication system via a chaotic circuit

Kaotik devre ile gerçek zamanlı analog güvenli görüntü iletişim sisteminin uygulanması

Yazar(lar) (Author(s)): *Aybaba HANCERLİOGULLARI[1], Khaled Mohamed EL HADAD[2], Erol KURT[3]*

ORCID[1]: 0000-0001-7008-480X

ORCID[2]: 0000-0002-0374-4350

ORCID[3]: 0000-0002-3615-6926

Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Hancerliogulları A., El Hadad K.M. and Kurt E., "Implementation of a real time analog secure image communication system via a chaotic circuit", ***Politeknik Dergisi***, 22(4): 1083-1092, (2019).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.557289

Kaotik Devre ile Gerçek Zamanlı Analog Güvenli Görüntü İletişim Sisteminin Uygulanması

Araştırma Makalesi / Research Article

Aybaba HANCERLİOGULLARI[1], Khaled Mohamed EL HADAD[2], Erol KURT[3*]

[1]Faculty ofArts and Sciences Physics Department, Kastamonu University, Turkey
[2]Department of Electronics, College of Engineering, Elmergib University, 40414 Libya
[3]Technology Faculty Electric-Electronics Enginering Department, Gazi University, Turkey

(Geliş/Received 23.04.2019 ; Kabul/Accepted 27.05.2019)

ÖZ

Eşazmanlı bir kaotik devreyi temel alarak yeni bir güvenli görüntü haberleşme sistemi tasarlanıp uygulanmaktadır. Yazarlardan biri tarafından yakın zamanda önerilen yeni kaotik devre direnç, bobin ve diyot çiftinden (yani R2L2D) müteşekkildir. Eşzamanlılık birimi hakim - esir düzenlenimi ile çalışmaktadır. Gerçek zamanlı haberleşmeyi sağlamak için, analog bir hakim devre ilkin sayıların kaotik dizilerini oluşturmak için uygulanmıştır. Sonrasında; bu analog araç bir bilgisayara bir analog / sayısal dönüştürücü yardımıyla iletilmekte ve gizli görüntü elde edilmektedir. Ayrıca; esir devre görüntünün gri seviyelerinin çıkarılması işlemi için bu kaotik dizilerin bir kopyasını almaktadır. Sayısal kaotik görüntü etkin bir yöntemle sayısal / analog dönüştürücü yardımıyla esir devreye iletilmekte ve şifresi çözülmüş olan görüntü gerçek zamanlı olarak elde edilmektedir. Bu tekniğin geleneksel olanlara göre üstünlüğü, gri renkli görüntüleri alıcıya gönderirken bile gerçek zamanlı olmasından dolayı sayısal verinin kaydedilmiş bir kopyasını gerektirmemesidir. Geleneksel teknikler depolanmış ve işlenmiş verileri kullanır ve bu süreç, günümüzün gelişmiş ağ ortamında güvenlik sorunlarına sebep olur. Böylece; şifrelenmiş bir görüntüyü gerçek zamanlı bir cihazda analog bir kaotik sistem kullanarak göndermek belli bir güvenlik üstünlüğüne sahiptir. Şifresi çözülmüş görüntülerle yapılan ilk analizler sürecin zamanla verimli ve güvenli olduğunu kanıtlamaktadır.

Anahtar Kelimeler: Güvenli iletişim, analog, kaotik devre, görüntü şifreleme, şifre çözme.

Implementation of a Real Time Analog Secure Image Communication System via a Chaotic Circuit

ABSTRACT

A new secure image communication system has been designed and implemented based on a synchronized chaotic circuit. The new chaotic circuit, which has recently proposed by one of the authors contains a resistor, two inductors, and two diodes (i.e. R2L2D). The synchronization part operates with a master – slave configuration. In order to achieve the real-time communication, initially the analog master circuit has been implemented to generate chaotic sequences of numbers. Then, that analog tool has been transmitted to a computer via an analog/digital converter and a hidden image has been obtained. Besides, the slave circuit has also received a copy of that chaotic sequences in order to use it in subtraction process of image gray levels. The digital chaotic image has been transmitted to the slave circuit via a digital/analog converter with an efficient method and the decrypted image has been obtained in real-time. The advantage of that technique over the conversional ones is that it does not require any saved copy of the digital data, even for sending them in gray images to the receiver, since it is real-time. The conventional techniques use the stored and processed data and that can cause security problems in today's advanced web media. Thus to send the encrypted image in a real-time device by using an analog chaotic equipment has certain security superiority. The analyses on the preliminary decrypted images proves that the process is efficient in time and secure.

Keywords: Secure communication, analog, chaotic circuit, image encryption, decryption

1. INTRODUCTION

The researchers have shown great interest on the nonlinear and chaotic circuits due to their broad application areas such as synchronization, noise characterization, optical beam production, Josephson junctions, etc. Indeed, studying on a nonlinear system and chaotic electrical circuits is the most economical and easy way [1-4]. On the one hand, these circuits can be defined by simple coupled differential equations. According to literature, the simplest circuit can be mentioned as resistor – inductor –diode circuit (RLD), which leads to a sequence of many period-doublings, thus it has been used to explore the universality of "chaos" in that context [5, 6]. When a resistor, diode and an inductor are joined in series, chaos occurs due to the nonlinear charge - voltage behavior of the diode[5]. Furthermore, using the invariants characterizing attractors as parameters for inputs, make it possible to get single-step and multiple-step predictions of chaotic time-series, which controls RLD circuits [7]. In other applications, for instance, Chua's diode and non-autonomous Chua's diode [6] there exists nonlinear

**Sorumlu Yazar (Corresponding Author)*
e-posta : ekurt@gazi.edu.tr

resistors, which ensure the complexity. When Chua's circuit was first invented in early 1980's, it was concerned by many researchers on the generation of True Random Number Generators (TRNG) for the cryptographic maneuvers[6]. Considering the artificial TRNG with many advantages, randomness take place through an unpredictable natural process in the hardware.

Random Number These generators provide sequential and statistically independent random numbers [8]. Apart from the studies above, many other circuits have also been proposed for different applications, but discussion over all those circuits is a comprehensive task and out of the consideration of present paper.Chaotic synchronization has recently gained more concern as area of research in secure communication. Some chaotic synchronizing and relevant factors are discussed by Feki [9]. However, two identical chaotic system synchronization was initially reported in 1990s [10]. Electrical engineers realized that the generated chaos can be a possible source of communication system security, because chaos is extremely sensitive to the initial conditions and parameters [11]. Secure communication using synchronization between chaotic systems was a newly found method of communication security. This "hardware key" secures communication that rapidly takes place. The "hardware key" was a new concept but engineers and scientists soon realized its importance for secure communication systems. There was a great scope of encryption through chaos; therefore, large number of researchers conducted researches on it. Electrical engineers of that time felt that it could help creating communication security because of its unique parameters. Later this type of chaotic hardware key was acknowledged as useful by researchers, engineers and experts all over the world [12]. Significant potentials of "hardware key" led to vast and multiple researches in the field of communication security that further opened new avenues for progress in this field.Many image encryption schemes based on chaos theory have been presented in literature. In 1992, Bourbakis and Alexopoulos [13] proposed an image encryption scheme utilizing SCAN language for encryption and compression of an image. During recent years, many logistic map algorithms were studied. The usage of digital chaotic systems instead of analog chaotic systems have also been proposed. Algorithms convert pixels into chaotic maps to make chaotic map lattice. This encryption is reprocessed using secret system parameters. Pisarchik and Zanin [14], Xiangdong, Junxing [15] have presented another algorithm using chaos theory and sorted transformations. Hu and Han [16] used pixel-based scrambling for digital medical images protection. Tong and Cui [17] introduced image encryption using dynamic cipher shifting. Pisarchik and Zanin [14] dynamically shifted compound chaotic cipher sequence. They moved all the pixels through 2D chaotic map using substitution and permutation, which moved new pixels as a permutation of the original ones. In the substitution process, the pixel values are altered sequentially by Fridrich [18], Gao, Zhang [19]. The chaotic algorithm with its power and tangent functions used a chaotic sequence generated by XOR operation [20]. Zhou, Wong [21] have proposed parallel image encryption algorithm using discretized Kolmogorov flow map, which first permutes a chaotic map and encrypts it in the cipher block chain mode. Communication security using encryption works by converting the data to an incomprehensible (not understandable) format with the help of a transmitter.The transmitter makes the data invisible and quite unreadable during the communication/transmission processes. This encryption is transmitted using any insecure link. On the recipient side, encrypted data is reconverted into comprehensible format and thus the information is transmitted securely. There are various methods for data hiding such as the *spatial domain*, *frequency domain* and *compressed data domain*. Among them, direct methods have certain advantages in the sense that they use all the image-based data and provide very accurate registration [22]. It has a disadvantage as well and that is their memory requirement, and besides, close initialization and techniques may not be easy to implement. In order to prove robust chaos encryption system, there are many tests to check. Histogram results and correlation values have shown that encryption of images can be unpredictable [23]. However, all those studies have come out a security issue that one can reach the digital data easier via internet and hardware or analog circuit-based solutions can serve better solutions, when they are used in real-time basis in order to prevent that online insecurity.In a recent study[24], Kurt and Bingol has proposed a new circuit, namely R2L2D circuit. A wide feeding amplitude and frequency regimes have been explored in this circuit. A new sweep up/down effect has also been discovered by them and that effect governs the identification of the dynamics in terms of periodic and chaotic regimes in this circuit for sweeping parameters [9, 24]. In the present paper, this new R2L2D circuit is applied to a real-time secure image communication application. Since this hardware and real-time based operation is secure than the software and digital stored systems, that new approach offers a good image security method in that field.

2. BACKGROUND ON SYNCHRONIZATION AND SECURE COMMUNICATION

The R2L2D circuit has been explored for its amplitude and frequency regimes [24] because of its sweep up/down behavior. In that manner, the periodic and chaotic regimes may invade each other for different frequencies. Thus, it defines an uncertainty region for the thresholds of the dynamic regimes depending on the

feeding voltages. That effect has an importance for the synchronization and encryption studies since the feeding voltages affect the regime. To be at the safe side, one should study on a chaotic region in the map given in thresholds of the dynamic regimes d epending on the feeding voltages. That effect has an importance for the synchronization and encryption studies since the feeding voltages affect the regime. To be at the safe side, one should study on a chaotic region in the map given in Ref.[25]. Strictly speaking, the synchronization of R2L2D can be studied for a wider parameter region in R2L2D circuit compared to the ordinary RLD circuit. It is also obvious from Refs. [24, 25] that the best synchronization performance can be obtained for lower frequencies and amplitudes. According to experiments, the chaotic regimes also affect the recovery of a masked signal as proven in Ref.[26].The determination of synchronization is defined via the Master circuit as follows. The system equations of the Master function (m) are formed as,

$$\frac{dx}{dt} = f(x(t)) \quad (1)$$

A Slave function (s) can be written together with master and the state equations are arrived as,

$$x = \begin{bmatrix} x_m \\ x_s \end{bmatrix} \quad (2)$$

Dynamical form of these systems can be summarized as,

$$\dot{x}_m = g(x_m, x_s) \quad (3)$$

$$\dot{x}_s = h(x_m, x_s) \quad (4)$$

According to the method of Pecora and Carroll [25], a copy of slave circuit x_s is driven together with master circuit x_m as follows,

$$\dot{x}_m = g(x_m, x_s) \quad (5)$$

$$\dot{x}_s = h(x_m, x_s) \quad (6)$$

$$\dot{x}_s' = h(x_m, x_s') \quad (7)$$

If time goes to infinity, and the difference $|x_s - x_s'|$ converges to zero, and x_s and x_s' become identical and synchronization is provided. As the first step, the formation of chaotic masking and decryption is made as in Fig. 1. Initially, the chaotic signal $c(t)$ is added to the regular sequence of image pixels values "information data", then it is transmitted to the receiver for the subtraction of chaotic data and decipher the image.

The state equations for the master circuit are given by,

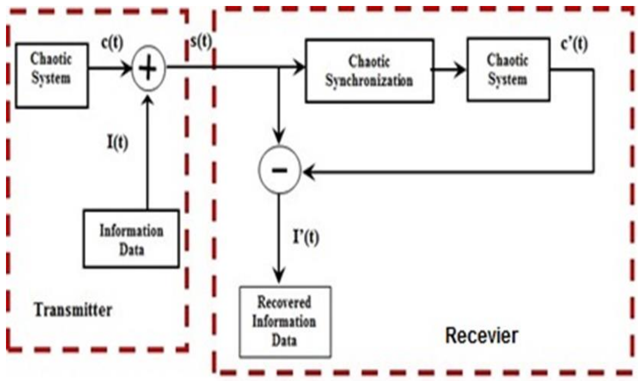


Figure 1. The block diagram of the non-autonomous chaotic secure communication system.

$$\begin{aligned} \dot{x}_m &= \alpha\, ln(x_m + 1) + \beta \sin(u_m) - z_m \\ \dot{y}_m &= -\alpha\, ln(y_m + 1) + \beta\, sin(u_m) - z_m \\ \dot{q}_m &= \left(\frac{L}{R} I_s\right) z_m \\ \dot{u}_m &= \Omega \frac{L}{R} \end{aligned} \quad (8)$$

Here x and y denotes the currents flowing from the branches and z is the phase of the feeding voltage. Besides, α=kT/e as the exponent of diode and β=V/L, where V denotes the maximal applied voltage and L is nothing else than the inductance of the inductor. I_s gives the saturation current of the diode. x_m, y_m, z_m, y_m, q_m and u_m gives two diode currents, total of diode currents, charge accumulated on a diode and voltage angular frequency. Similarly the equations for the slave circuit are

$$\begin{aligned} \dot{x}_s &= \alpha\, ln(x_s + 1) - z_s \\ \dot{y}_s &= -\alpha\, ln(y_s + 1) - z_s \\ \dot{q}_m &= \left(\frac{L}{R} I_s\right) z_s \end{aligned} \quad (9)$$

The slave circuit gets the charge amount q from the main branch over two branches of slave circuits. Thus, that process can be described by,

$$\begin{aligned} \dot{x}_s &= \alpha\, ln(x_s + 1) - z_m \\ \dot{y}_s &= -\alpha\, ln(y_s + 1) - z_m \\ \dot{q}_s &= \left(\frac{L}{R} I_s\right) z_s \end{aligned} \quad (10)$$

Since the secure communication requires a high order synchronization to decipher the signal, the functions x_s, y_s and q_s are controlled by the main current branch of the master circuit. When the information signal is transmitted to the system, the equations are defined as,

$$\begin{aligned} \dot{x}_s &= \alpha\, ln(x_s + 1) - s(t) \\ \dot{y}_s &= -\alpha\, ln(y_s + 1) - s(t) \\ \dot{q}_s &= \left(\frac{L}{R} I_s\right) z_s \end{aligned} \quad (11)$$

In the chaotic modulation part, two methods are generally used in order to combine the information signal and the chaotic carrier signal. One is called chaotic parameter modulation [27] and the other is chaotic non-autonomous modulation [26] as used in the present study. Signal *I(t)* represents the information signal and modulates certain parameters within the transmitter of the chaotic system. At the receiver part, the slave part is synchronized in terms of Eq. 10. Therefore, the synchronization error approaches to zero.In the present study, the classical cryptographic technique and chaotic synchronization are combined and that enhances the communication security. In order to apply the chaotic output to the image, the process in Fig. 2 has been applied [28].

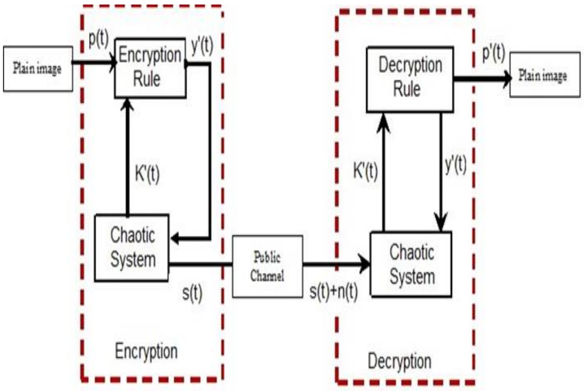


Figure 2. Plain image transmission and receive via the chaotic encryption and decryption

The encryption signal drives the chaotic system, when a transmitter transmits signal in a public channel, which any intruder can get but since that intruder is unable to get the hardware key, it becomes close to impossible to get $p(t)$ from $s(t)$. On the receiver's end, the signal $r(t) = s(t) + n(t)$ is received, while $n(t)$ channel noise synchronizes the chaotic systems. After the chaotic synchronization, signals $k(t)$ and $y(t)$ are recoverable at the receiver end though with some noise denoted by $k'(t)$ and $y'(t)$ for the real-time based plain image. The chaotic signal starts from the main branch of master circuit, the masking and recovery circuit including the master and slave parts (Fig 3). In addition to Master circuit (*M*) and Slave circuit (*S*), the Adder circuit (*Au*) and the Recovery circuit (Su) are also shown in Fig. 3. The *Au* circuit gets the chaotic signal form *M* and combines it with the *I(t)* signal and later, the masked signal is transmitted to the *Su* circuit and the chaotic part is subtracted through the slave circuit and a clear *I(t)* signal is obtained. R2L2D analog chaotic circuits have been simulated in NI Multisim software [29]. Fig. 4 shows the experimental circuitry in line with Fig. 3.

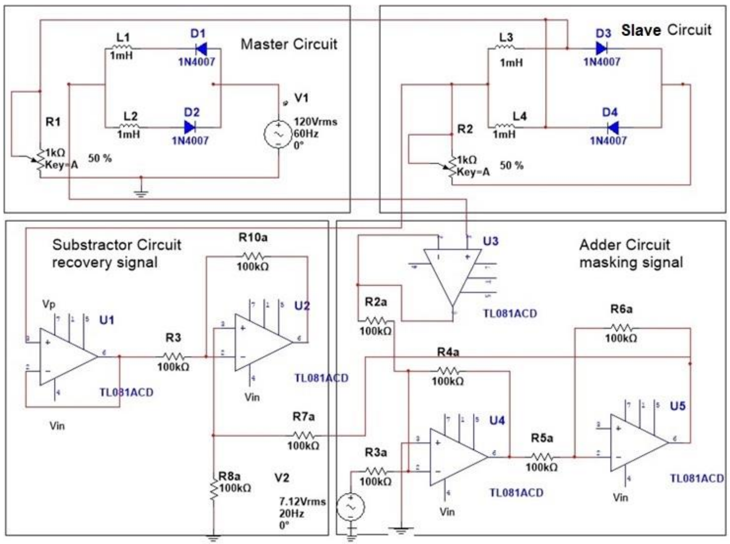


Figure 3. Secure communication system scheme

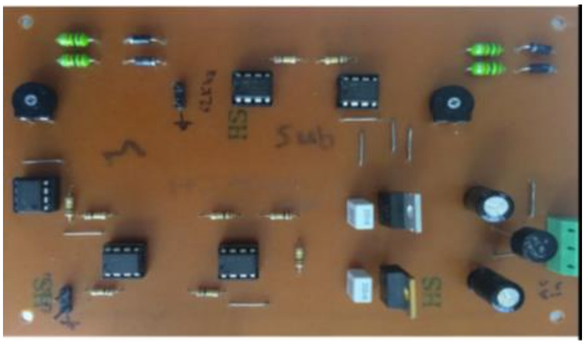


Figure 4. Circuit system communication

3. IMAGE ENCRYPTION AND DECRYPTION TECHNIQUE

The algorithms for the image encryption use the digital random generation or chaotic maps with mathematical algorithm based on complex mathematical steps, which have drawbacks such as small key spaces, slow performance and weaker security. The new image encryption technique proposed in this paper depends on a R2L2D chaotic circuit for secure image transfer without saving any images and or secure keys since it is a real-time-based technique. The circuit parameters are enough to recover the data and no other parameter, image or secure key are not required for the receiving side. The new technique for the secure image encryption / decryption is depicted in Fig. 5. The arrival of the ciphered image is sufficient to have the original image.

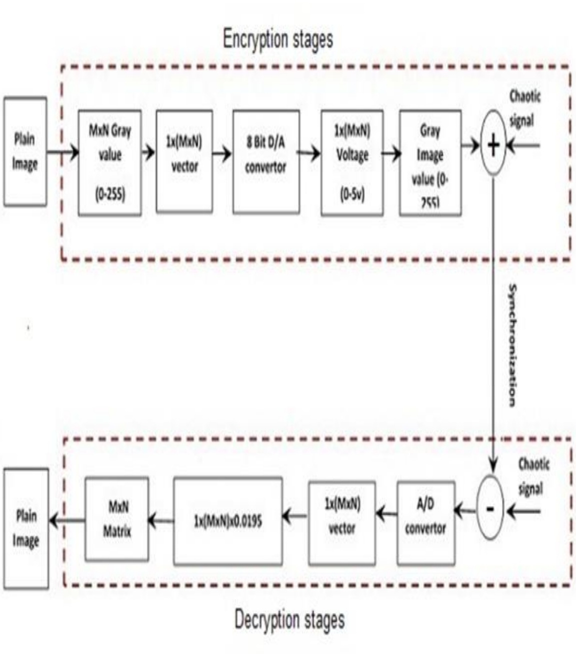


Figure 5. The encryption/decryption technique

3.1. Image Encryption

Gray scale images have gray levels from 0 (black) to 255 (white) in the secure image communication study. These values mean that every pixel is eight bits (i.e. one byte). In the present study, we focused on applying gray scale matrix by using MATLAB software and that matrix then converted to an analog signal. Initially, the real images were converted into the gray images to obtain the gray image matrix with size *M*x*N*. Here *M* represents rows and N columns. The matrix is transferred into double type matrix for the mathematical operation. Conversion of gray image matrix to the analog voltage can be done via an 8 bit D/A converter circuit. It is responsible to convert image matrix to the analog voltages via real time transfer. R2R resistors DAC [30] convert digital to analog voltage. It consists of resistors for every bit of output and they are linked with the summing point for providing output. The output v_{out} is determined by Eq. 12 for *N* bits.

$$v_{out} = v_{ref} \sum_{i=0}^{n} b_i \frac{1}{2^{i+1}} \qquad (12)$$

8bits represent image gray scale pixels between 0 and 255, thus by 8 bits one can represent 255 values by introducing a conversion constant. Fig. 6 shows the R2R D/A, where R=0.5 KΩ and 2R=1 KΩ

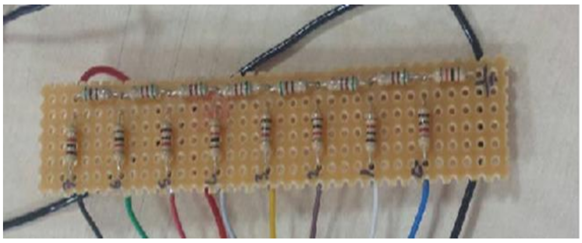


Figure 6. 8 Bits R2R D/A

The image gray scale pixels are converted from (0-255) interval to (0-5V) by using that D/A converter by following the schema in Fig. 7. The converter converts 5 volts into 255 grays with a step value of 5/255 = 0.0195 V. The output amplitudes should be equal to the step voltage value multiplied by the binary input (i.e. for instance, 129 = 1000 0001 in binary form). Thus, the output voltage should be 129 x 0.0195 = 2.451V in that case. The conversion is linear as shown in Fig. 8

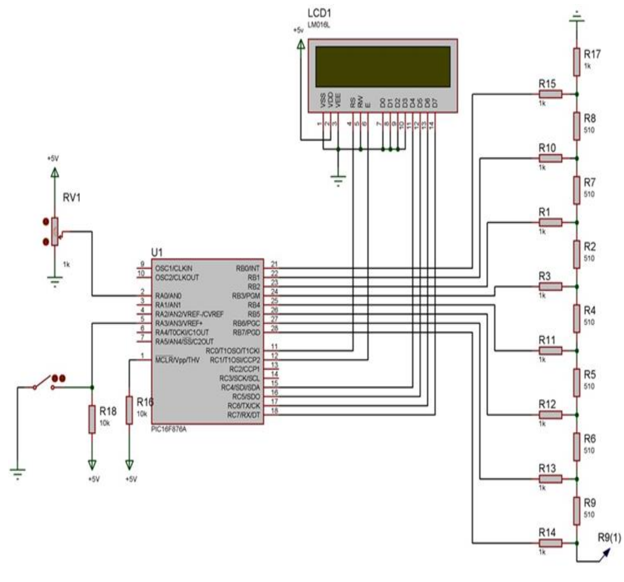


Figure 7. An 8 bit D/A converter schema

To confirm our values and sorting values, we used LCD screen that shows a number of rows and columns during the conversion process. In addition, we used a simple potentiometer to reduce the delay time during the transmission of the gray image signal. Using the Potentiometer allows one to initiate the sending time and their readability by MATLAB code. Simulation of the system has been performed by a Proteus software. The output voltages are obtained same with the findings from Eq. 8.

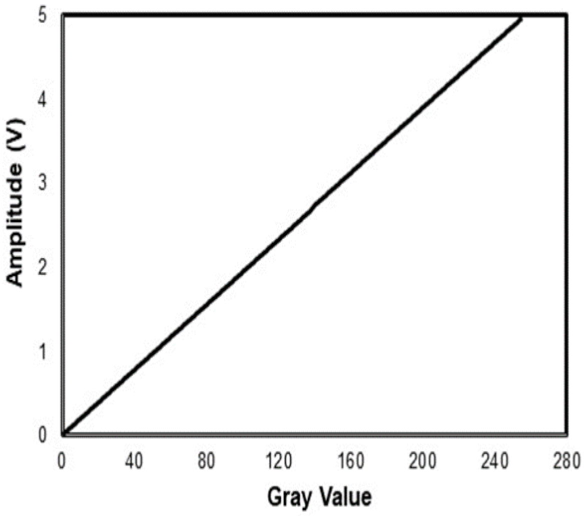


Figure 8. The plot of gray level versus amplitude for the conversion in D/A converter.

The gray value, number of rows/columns, and delay time have been observed on the LCD screen as in Fig. 9.

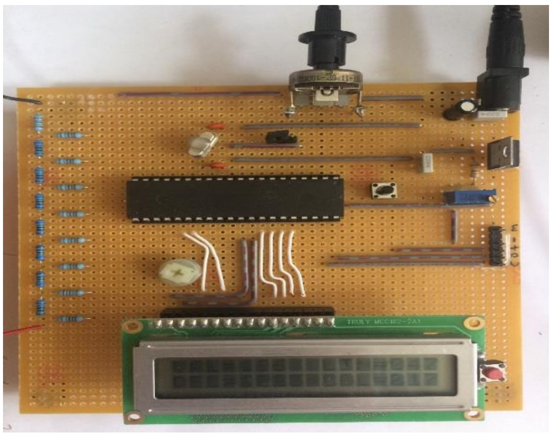
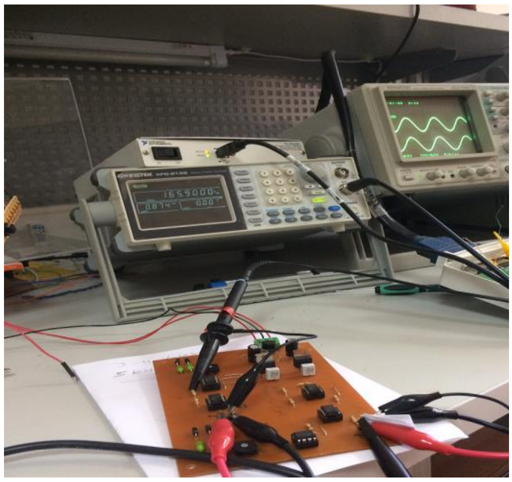
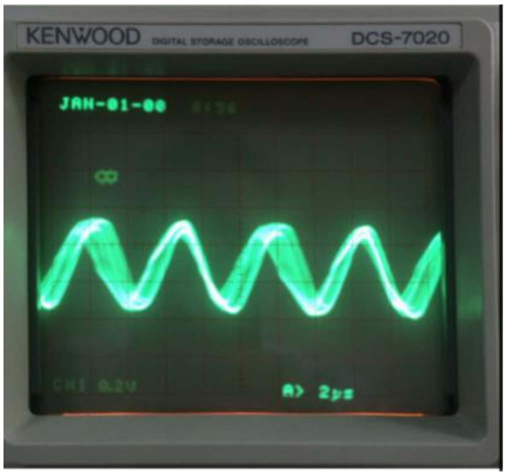


Figure 9. An 8 bit D/A circuit in board.

Then, the initial condition for chaotic signal in R2L2D circuit should be configured in the Master unit by applying sine wave signal in the master unit and also for configuring initial conation (frequency, amplitude voltage and value of resistor) to obtain chaos signal as shown in Fig. 10(a,b). Image gray signal comes from the D/A converter to the adder circuit. After the adding process, the encrypted signal is send through the insecure channel. Fig. 11 shows the total transmitting circuit including the adder and D/A converter.



(a)



(b)

Figure 10. (a) Setup and (b) a sample chaotic signal from the oscilloscope.

3.2. Image Decryption

After the encrypted image is transmitted to the receiving body, it should be decrypted. In order to decrypt the image, there is no condition required for the receiving body. Since the system operates real time, then receiver can directly decrypt the masked image. The decryption uses the following steps:

Step 1: In the receiver part including the slave circuit, the pure chaotic signal is subtracted from the decrypted signal and the gray levels of the image signals are obtained.

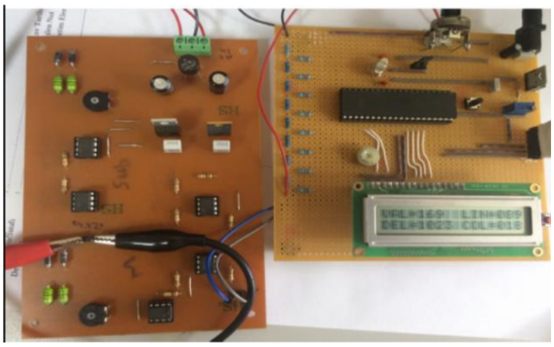


Figure 11. The combination of the transmitter and D/A converter

Step 2: The analog image signals from the subtraction circuit are converted to the digitalized media into a data file. That A/D converter unit is shown in Fig. 12. An Arduino Uno works well with an absolute accuracy within the error ranges +/- 10mV.

Step 3: After the extraction of the voltage values for the gray levels, they are converted to the real gray level values, thereby the decrypted image is obtained at last step. The receiver part subtracts the encrypted signal from the masked signal with a high accuracy as shown in Fig. 13. According to Fig. 8, those values are converted into the real image gray levels in the MatLab media.

4. EXPERIMENTAL RESULTS

The quality of the encryption of the images depends on sending and reading processes. Strictly speaking, the signal, which is transmitted and received from/to the analog circuit can lose its originality, thus, it may cause a certain error. Therefore the quality of the conversion circuit and its connection are vital to fulfill the image quality in masking and recovering.

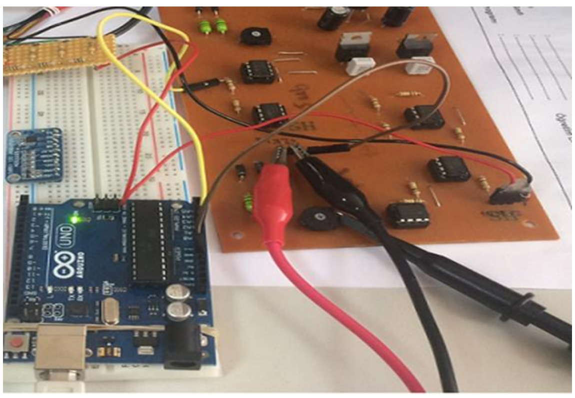


Figure 12. The subtraction circuit and the Arduino A/D converter in the receiver part

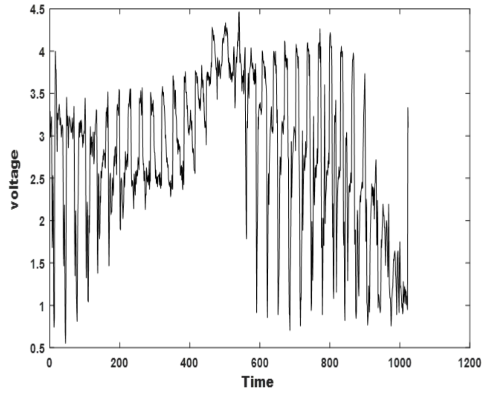


Figure 13. The decrypted gray level signals after the A/D converter

Fig. 14(a,d,g,j) shows the original test image, the encrypted ones are shown in Fig. 14(b,e,h,k) and finally Fig. 14(c,f,i,l) shows the decrypted image. Note that the images are tested for their 32x32 pixel image forms.

5. RESULTS AND DISCUSSION

The tests on the encrypted images are important in order to make the communication in a safe way from the public channel shown in Fig. 2. In that part, the histogram analyses, pixel correlation tests and error measurements have been carried out.

5.1. Histogram analysis

Histogram analysis is important in the sense that the factors measuring the image encryption, prevent information leakages to insecure sources or opponents, because the encrypted images have no statistical resemblance with the originals. In order to test the histogram, the original and encrypted images are considered. After the measurements of histograms, Fig. 15(a-h) has been plotted. Note that the encrypted images have more distributed histograms, which prove good encryption.

From the histograms, it is found that the most powerful encryptions were performed for Figs. 14(d) and (g). Strictly speaking, the histograms of the genuine images are in the form of clustered spikes, the encrypted images have a broader distribution to all gray levels.

They are also different from the histograms of the genuine images by annihilating these clustering appearances. Histograms of encrypted images do not give any kind of information regarding the original images. They can be acceptable as secure images in the communication since no effort to decrypt those images by any unauthorized person can be successful in that manner.

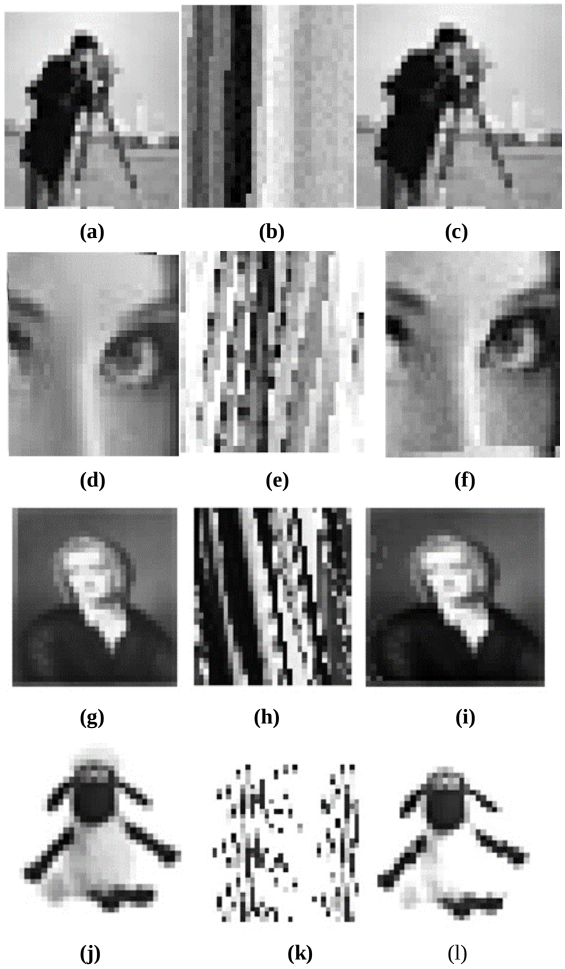


Figure 14. The images for testing. The original transmitted images (a,d,g,j), the crypted ones (b,e,h,k) and the decrypted forms (c,f,i,l).

5.2. Pixel Correlation

In the digital images, usually high redundancy data exists and those show high correlation between neighboring pixels. By definition, a good cryptal system should reduce that correlation. Indeed, that becomes a major defense against the statistical attacks. The correlation coefficients of the encrypted pixels for different sizes of images have been calculated for both the original and the encrypted images within that test. The data correlation is defined as ρ or $corr$, which is the coefficient of correlation. Besides, X and Y are datasets, and μ is the mean value in the standard deviation. When variables X and Y are highly correlated, the ρ value would be closer to one. For instance, a positive correlation coefficient indicates that as one variable increases, the other also increases or vice versa. The opposite is true if their ρ value is closer to zero.Zero indicates that the variables are not correlated in this context. The coefficient correlation can be read as,

$$\rho_{x,y} = corr(X,Y) = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E((X-\mu_X)(Y-\mu_Y))}{\sigma_X \sigma_Y} \quad (13)$$

Here E is the expected value and cov stands for the covariance. The correlation between the original and the encrypted images are given in Table 1 for their 32x32 dimensions.

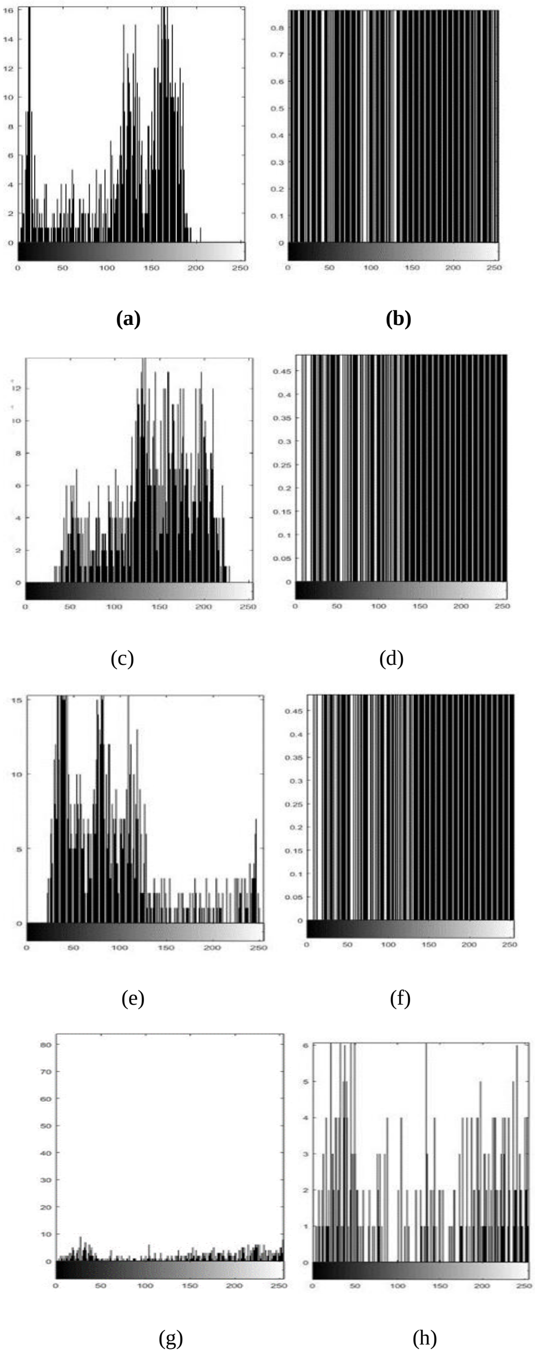


Figure 15. Histogram test results of the decrypted images given in Fig14.

Generally speaking, while the correlations are higher between the original and decrypted images, the correlations decay to 0.35 or lower values between the original and encrypted images as expected.

Table 1. Correlation coefficients of the original and encrypted images

Image Name	Correlation Coefficients Between original And Encrypted Images	Between Original-And Decrypted Images
Cameraman	0.3584	0.897
Lena	-0.374	0.847
Man	0.215	0.698
Sheep	-0.0152	0.713

5.3. Error Measurement

The main error source is the real time conversion of the images via the analog to/from digital platform. Indeed, the experimental measurements of output analog signals should also have an absolute error as in all real time devices. Such errors have been measured and calculated as in Table 2 .

While the lowest error is obtained for Lena, the largest one is calculated for sheep. However, for a real time cryptal system error amount about 5% is within the acceptable limits

Table 2. Error Measurements with respect to test images.

Images	Error (Original- Decrypt)
Cameraman	4%
Lena	3.7%
Man	3.9%
Sheep	5.3%

6. CONCLUSIONS

In the present study, a new chaos based secure image communication technique has been designed and implemented. The new technique uses a new proposed chaotic synchronization circuit in master/slave form and masks the plain image gray levels into the chaotic signal, transmit it with a public channel and recover it with a sufficient accuracy within 5% in a real-time based environment. Since the system operates in real time, it is more secure than any other cryptal systems. Because synchronization between the sender and receiver are ascertained for only the sending time period, thus one cannot recover the image without having the same chaotic signal. In addition, the analog equipment is important to have the same chaotic output. In this regard, if the public does not have the correct circuitry and connection time and transmission time duration, they would never recover the plain image.

Besides, the technique is useful because it does not need to save any digital data while sending gray images to the receiver, because they are converted to the noisy signals in a synchronized way. Thus, that technique is better, reliable and fast compared to the other traditional techniques.

In fact, a digital media is always unsecure due to software developments among the hackers, improvements in internet systems, etc., and that has the digital environment been weak for such secure communication systems. Thereby, that new real time based technique can be used to make more secure image communication in this manner. The only disadvantage which has was encountered in that technique was a little noise in the decrypted image, however if larger memory is used, that disadvantage can be annihil.

REFERENCES

[1] Murali, K., Lakshmanan, M. and Chua, L.O., "The simplest dissipative nonautonomous chaotic circuit", ***IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications***, 41(6): 462-463, (1994).

[2] Kurt, E., Acar, S. and Kasap, R. ,"A comparison of chaotic circuits from a statistical approach.". ***Mathematical and Computational Applications,***. 5(2): 95-103, (2000).

[3] Adak, S., Cangi, H. and Yılmaz, A.S.,"Design of an LLCL type filter for stand-alone PV systems' harmonics." ***Journal of Energy Systems,***; 3(1): 36-50, (2019).

[4]. Kiers, K., Schmidt, D. and. Sprott, J.C ,"Precision measurements of a simple chaotic circuit. ***American Journal of Physics***, 72(4): 503-509, (2004).

[5] Linsay, P.S., "Period doubling and chaotic behavior in a driven anharmonic oscillator." ***Physical Review Letters***, 47(19):1349.,(1981).

[6] Kurt, E., "Nonlinearities from a non-autonomous chaotic circuit with a non-autonomous model of Chua's diode". ***Physica Scripta,***.74(1): 22, (2006).

[7] Hanias, M., Avgerinos, Z.and Tombras, G.,"Period doubling, Feigenbaum constant and time series prediction in an experimental chaotic RLD circuit". ***Chaos, Solitons & Fractals***, 40(3):1050-1059, (2009).

[8] Andreatos, A.S.and Volos. C.K,"Secure text encryption based on hardware chaotic noise generator. in ***2nd International Conference on Cryptography and Its Applications in the Armed Forces***, (2014).

[9]. Feki,M.,"An adaptive chaos synchronization scheme applied to secure communication." ***Chaos, Solitons & Fractals***, 18(1):141-148, (2003).

[10]. Cuomo,K.M.,"Oppenheim, and S.H. Strogatz, Synchronization of Lorenz-based chaotic circuits with applications to communications."***IEEE Transactions on circuits and systems II: Analog and digital signal processing,***. 40(10): 626-633, (1993).

[11]. Mu, X. and Pei, L. "Synchronization of the near-identical chaotic systems with the unknown parameters." ***Applied Mathematical Modelling***,34(7): 1788-1797, (2010).

[12]. Yang, T., "A survey of chaotic secure communication systems." ***International Journal of Computational Cognition,*** 2(2): 81-130, (2004).

[13]. Bourbakis, N. and C. Alexopoulos, Picture data encryption using scan patterns**. *Pattern Recognitio***n,. 25(6): 567-581, (1992).

[14]. Pisarchik, A. and Zanin, M."Image encryption with chaotically coupled chaotic maps". ***Physica D: Nonlinear Phenomena,*** 237(20): 2638-2648, (2008).

[15]. Xiangdong, L.,"Image scrambling algorithm based on chaos theory and sorting transformation." ***IJCSNS International Journal of Computer Science and Network Security,*** 8(1): 64-68, (2008).

[16]. Hu, J. and Han, F.," A pixel-based scrambling scheme for digital medical images protection"**. *Journal of Network and Computer Applications,***32(4): 788-794, (2009).

[17]. Tong, X. and M. Cui," Image encryption scheme based on 3D baker with dynamical compound International Journal of Bifurcation and chaos, cipher generator". ***Signal processing***,. 89(4): 480-491, (2009).

[18]. Fridrich, J., "Symmetric ciphers based on two-dimensional chaotic maps." ***International Journal of Bifurcation and chaos***,. 8(06): 1259-1284, (1998).

[19]. Gao,H.,"A new chaotic algorithm for image encryption"***Chaos, Solitons & Fractals***, 29(2): 393-399, (2006).

[20] Rulkov, N.F.,"Generalized synchronization of chaos in directionally coupled chaotic systems." ***Physical Review E,***. 51(2): 980, (1995).

[21] Zhou, Q,"Parallel image encryption algorithm based on discretized chaotic map".***Chaos, Solitons & Fractals,*** 38(4): 1081-1092, (2008).

[22]. Shelke, F.M.,. Dongre, A.A and. Soni, P.D " Comparison of different techniques for Steganography in images"., ***International Journal of Application*** , (2014).

[23]. Celik, K. and Kurt. E." A new image encryption algorithm based on lorenz system. in Electronics", Computers and Artificial Intelligence):***8th International Conference on. IEEE***, (2016).

[24] Kurt, E. and Bingol, C. "A New Sweep Up/Down Phenomenon between the Chaotic and Regular Regions in a New R2L2D Circuit," ***Politeknik Dergisi***, 19(3): 305-310, (2016).

[25] Pecora, L.M. and Carroll, T.L,"Synchronization in chaotic systems"***Physical review letters***, 64(8): 821, (1990).

[26]. Wu, C.W. and. Chua, L.O."A simple way to synchronize chaotic systems with applications to secure communication systems."***International Journal of Bifurcation and Chaos,*** 3(6): 1619-1627, (1993).

[27] Yang, T. and. Chua, L.O "Secure communication via chaotic parameter modulation.IEEE"***Transactions on Circuits and Systems:Fundamental Theory and Applications,*** 43(9): 817-819, (1996).

[28] Yau, H.T.and Yan, J.J."Chaos synchronization of different chaotic systems subjected to input nonlinearity"***Applied Mathematics and Computation***, 197(2):775-788, (2008).

[29] Kurt,E. and Bingol ,C.," Exploration of Synchronization Secure Communication and Signal Recovery in New R2L2D Circuit," ***58th Int. Sci. Conf. Riga Tech. Uni. Power and Elec. Eng. RTUCON***. Riga, Latvia. (2017).

[30]. Hendriks, P.,"Specifying communications dacs.***IEEE spectrum,"*** 34(7): 58-69.(1997).Power and Elec. Eng. RTUCON2017, 12-13 Oct. 2017, Riga, Latvia.