Cryptosystems using an improving hiding technique based on latin square and magic square

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ABSTRACT

Hackers should be prevented from disclosing sensitive data when sent from one device to another over the network. Therefore, the proposed method was established to prevent the attackers from exploiting the vulnerabilities of the redundancy in the ciphertext and enhances the substitution and permutation operations of the encryption process the solution was performed by eliminates these duplicates by hiding the ciphertext into a submatrix 4x4 that chooses randomly from magic square 16x16 in each ciphering process. Two techniques of encrypted and hiding were executed in the encryption stage by using a magic square size 3×3 and Latin square size 3x3 to providing more permutation and also to ensure an inverse matrix of decryption operation be available. In the hiding stage, the ciphertext was hidden into a 16×16 matrix that includes 16 sub-magic squares to eliminate the duplicates in the ciphertext. Where, all elements that uses were polynomial numbers of a finite field of degree Galois Fields GF (2⁸). The proposed technique is robust against disclosing the repetition encrypted data based on the result of Avalanche Effect in an accepted ratio (62%) and the results of the output of the proposed encryption method have acceptable randomness based on the results of the p-values (0.629515) of the National Institute of Standards and Technology (NIST) randomness tests. The work can be considered significant in the field of encrypting databases because the repetition of encrypted data inside databases is considered an important vulnerability that helps to guess the plaintext from the encrypted text.

Keywords:
Affine cipher function
Encryption process
Finite fields
Irreducible polynomial
Latin square

1. INTRODUCTION

Encryption that uses a peculiar number system is a good method to encode and decode data and provides additional security against attacks during transmission and providing opportunities for full encryption and decryption whilst hiding all technical details [1]. Numerous techniques are used to secure file transfer, including the types of encryption techniques designed to keep files secure. Substitution and transposition are two mechanisms used in symmetric encryption. Substitution involves changing plain text values to cipher text values. By contrast, the transposition moves the locations of plain text values [2].

Nowadays, attackers are trying to break the encryption algorithm by retrieving the key, or by analyzing a collision or the existence of repeated bits / characters (bytes) in the encrypted message to gain the algorithm of encryption or the key utilized for it. Therefore, the encryption method must be efficient and exclude repeated terms and the attacker cannot track the repetition [3]. The traditional cryptographic algorithm suffers from the problem of data redundancy in the ciphertext. This proposed method aims to develop an algorithm to exclude redundancy in the ciphertext. Where, new encryption and hiding algorithms
are implemented, using magic square and Latin square to increase the permutation and substitution to make encryption more secure and complex. In multiple encryption methods, many mathematical models and operations are used to improving encryption methods such as matrix multiplication, magic square, and Latin square. In this paper, we used the magic square and Latin square to improve the proposed encryption method and hide encrypted data.

1.1. Magic square and latin square

A magic square is a square matrix of integers with the same sum of the values in the rows, columns and main diagonals. As shown in Figure 1, a magic square of the fourth-order (i.e., 4×4) has a magic sum of 24, which is the total sum of the values in the rows, columns and main diagonals. A total of 880 different fourth-order magic squares are provided [4]. A Latin square is an n×n array of order n, in which all rows and columns contain {0, 1, 2 ... n − 1} precisely once and the also the symbols occur precisely once in each row and column. A Latin square is called diagonalised when the square has a main diagonal in a transversal form. Latin squares can be constructed using number theory using only one step from the magic square, particularly by using the modulo n of the magic square. In this manner, the Latin square obtained are of two types, namely, diagonalised and doubly diagonalised Latin squares of any odd order n [5]. That is, a magic square is an n×n array with integers {0; 1 ... n² − 1}, such that, each number is filled once in each row and column and the sum of each row, column and main diagonal or main antidiagonal is the same constant value. An example for order 3 as in Figure 2 [6].

| 1  | 2  | 16 | 15 |
|----|----|----|----|
| 13 | 14 | 4  | 3  |
| 12 | 7  | 9  | 6  |
| 8  | 11 | 5  | 10 |

A Latin square design is an approach of mapping elements to appear in an equal form into a square matrix. Elements appear one time in each row and column. The processes are assigned at random into the square, with each process appearing one time per row and column [7]. No algorithm is used to build all kinds of magic square. Thus, the algorithm that executes for even squares is different from the algorithm that works on odd order.

There are three methods for constructing magic squares according to the matrix dimensions are those of the odd order, singly even order and doubly even order [8]. Magic Squares of the Odd Order a simple type of magic square is of the form 2m+1, where m is a positive integer. The De la Loubère’s method is an example of an odd order, in which the matrix size may be 3×3, 5×5, and 7×7, amongst others.

Odd order magic squares were builid by using different methods, such as the pyramid, de la Loubere’s, or staircase method [9]. Magic Squares of a Doubly Even Order the order of the doubly even ordered squares is of the form 4n (e.g., 4, 8, ...) or may be divided by 2 and 4. An example is the method developed by Albrecht Dürer. The size of the square matrix is 4×4, 8×8 and 12×12, amongst others [10]. Magic Squares of a Singly Even Order. Singly even square in the order n is of the form 2(2m+1) =4n+2 (e.g., 2, 6, 10, 14, 18, 22, amongst others). The order can be divided by 2 but not 4. An example of this order is Philippe de la Hire’s method. The size of the matrix is 6×6, 10×10 and 14×14, amongst others [11].

Different approaches used to construct magic squares have been developed during the past years. An example is the dotting method, which depends on cells marked by dots for the magic square. To construct a 4×4 magic square, dots are first placed on the main diagonals. Thereafter, the cells are computed from a corner and numbers are written in every marked cell. When the last cell is reached, the cells are reviewed in reverse and the numbers are placed sequentially in each cell without dots. Figure 3 illustrates the arranged dots in the square. The magic square (12×12) is obtained via computing the cells starting from a corner and ending in the opposite corner see Figure 4 [12]. All mathematical operations used in the proposed method were performed on a polynomial numbers of degrees GF (2⁸).
1.2. Finite fields

Finite fields are a collection of finite elements also called Galois fields (GF), which was named after Evariste Galois (1811-1832). Galois studied the scope of polynomials and discovered many of their principles. Numerous applications have used finite fields, such as cryptographic algorithms (Diffie and Hellman, 1976; ElGamal, 1985; Miller, 1986; Kravitz, 1993) and advanced encryption standard (AES) [13].

The finite fields executed for the order \( p^n \) is defined as GF \( (2^n) \) as a set of \( 2^n \) elements. The two binary operations + and \( \times \) are defined in this set. Each nonzero element of the field has a multiplicative inverse [14]. All operations of finite fields produce an element in the field arrangement based on the \( p^n \), \( p \) indicates a prime number and \( n \) indicates a positive integer [15]. One of the cases in finite fields is when the prime \( (p) = 2 \), in which the elements of GF \( (2^n) \) are expressed as binary numbers. One of the uses of GF \( (2^n) \) is a polynomial. A polynomial number in GF \( (2^n) \) is showed in (1), which can be represented uniquely as \( n \) binary coefficients \((a_{n-1}a_{n-2} \ldots a_0)\) [14].

\[
f(x) = a_{n-1}x^{n-1} + a_{n-2}x^{n-2} + \cdots + a_1x + a_0 = \sum_{i=0}^{n-1} a_i x^i \quad \ldots \quad (1)
\]

Finite field multiplication represents multiplying two polynomials elements and sums them like powers of \( x \) as a result. When multiplication result greater than \( n-1 \), so, the result is minimized via the module of irreducible polynomial \( m(x) \) of grade \( n \) then the result divided by \( m(x) \) and kept the remainder [14]. “An irreducible polynomial is a polynomial \( f(x) \) over a field GF \( (2^n) \), if and only if \( f(x) \) can not be expressed as a two polynomials product, both over GF \( (2^n) \) and both of degree lower than of \( f(x) \)”. Moreover, a polynomial is irreducible when it is divisible by itself and 1 (without remainder) [14, 16].

1.3. Related works

a) Dharini (2014) proposed the encryption methods RSA for secure data transmission, in which SSL over RSA and combined magic square provide additional security to the system; moreover, the confidentiality and integrity of data sent to and from the cloud are ensured [17].

b) Chenglian Liu (2011) proposed a novel approach of streams cipher application for random access file that can be easily implemented according to the magic square method, also improve the model of the cipher stream to strengthen the protection efficiently and has a high speed of key stream generator [18].
c) Shahla (2017) proposed an approach to creating a magic square of order 32, which represents the difficulty in tracing this square in the cryptography and improving efficiency by providing robust security to the encryption. The magic squares have numerous random numbers rather than the ASCII values and are used to generate the keys of the public-key encryption algorithms [19].

d) Authors (2013) this paper aim to enhance an algorithm to eliminate the repetitive characters or symbols in the ciphertext by using extra algorithms such as Function Encryption, NIJSAA, Bit Rotation, and Reverse method, the encryption is very difficult to break and more secure [3].

e) Ako (2016) the author has proposed a new method that combines encryption and information hiding to increase security, privacy, accuracy, and confidentiality. A hash least significant bit method has been suggested for the hiding encryption data process with the use of an affine cipher to provide more encryption and increase data security in the network environment [20].

f) Authors (2016), proposed approach is used that combines the encryption method with a method of hiding encrypted data to increase the security and maintain confidentiality, integrity, and availability of data against external attacks and unauthorized access. The plain text was encrypted with the RSA algorithm and the ciphertext was hidden into the image using the advanced LSB method. Where the plain text was encoded and divided into parts P1 and P2, the XOR operation was performed on the part (P1) of the odd locations and (p2) using even location for LSB+1 [21].

g) Jeena Pappachan, Jinu Baby (2015), suggested one of the kinds of chaotic maps (Tinkerbell Maps) with the magic square encrypt the images. The proposed method provides efficiency and security for encryption images, the proposed method consists of a 128-key secret key or a 16-character hexadecimal key that divides into 16 8-bit subkeys. The magic squares and two-dimensional maps are created, row shifting, pixel adjustment [22].

h) The authors (2012) proposed encryption grayscale and color images method using a symmetric-key Latin square image cipher (LSIC), this method improved novel Latin square image encryption and a novel method of merging probabilistic encryption in image encryption by including random noise by LSB technique. The proposed LSIC has a secure cipher due to large keyspaces, excellent confusion, and diffusion approach and powerful against channel noise and brute-force attacks [23].

i) Al-Hasan (2018), proposed a new steganography approach is proposed by converting the cover image from RGB color space to YCbCr color space. Then, hide the encrypted data using the Affine Cipher and Magic Square Matrix are applied to embed the encrypted data onto the cover image using the ISB approach. Then the salt-and-pepper noise is added to the cover image. The results show that the proposed method withstands against attacks [24].

ej) Tomba I (2017), an improved cryptosystem by uses 5 pseudo letters {Au, Ea, Ee, Oo, Ou} in the sequence of 26 English letters. The proposed pseudo letters are using magic squares or any type of matrices in encryption and decryption operation. Using pseudo letters will affect the ASCII characteristics thereby will provide an additional layer of security of the improved cryptosystem [25].

2. PROPOSED METHODOLOGY

The proposed encryption method contributes to security enhancement and eliminates the symbols repetition of ciphertext by using many new methods such as magic square, Latin square to encryption data and constructing random magic square to hiding ciphertext inside it, which provides additional safety features. The majority of the encryption methods suffer from the repetition of the elements into the ciphertext. So, random magic squares were used to hiding the repetition in the ciphertext. In the proposed method, the encryption and decryption processes were executed in two phases. The first phase is done by using a 3×3 Latin square derived from the odd ordered 3×3 magic square to arrange the 9 key elements of the polynomial numbers of degree GF (2^5). The plaintext of the 9-byte polynomial numbers is arranged in odd ordered 3×3 magic square and multiplying with Latin square 3×3 using the operations of finite fields with an irreducible polynomial of GF (2^5). The second phase involves constructs magic square of a doubly even order 12×12 includes 16 sub-squares of even magic square to hide the encrypted text of the first phase randomly. Figure 5 presents the block diagram of the encryption operation. The coding scheme alone does not provide sufficient security. Thus, magic square provides the permutation of the character encoding based on the magic square schemes.

2.1. Encoding

All plain text were labeled using the ASCII code for coding the letters to polynomial numbers of GF (2^5). Thereafter, the numbers were arranged in 3×3 matrix [PO] based on podision. Then the encoded numbers of plaintext are arrange in a 3 3 matrix [p] based on the construction of the odd order 3×3 magic square (M).

\[[PO] \rightarrow [p]\]
2.2. Encryption

The encryption process includes two phases of encryption and hiding the encrypted text.

Phase 1: The encoded elements of the plain text were arranged in a $3 \times 3$ matrix $[p]$, and the key elements are arranged in an odd order $3 \times 3$ magic square $[M]$. Thereafter, the $3 \times 3$ Latin square $[L]$ was derived from the magic square by taking modulo 3 as (2). The encrypted text was executed by multiplying the $3 \times 3$ Latin square $[L]$ and encoded matrix $[P]$ with an irreducible polynomial ($m(x) = x^8 + x^4 + x^3 + x + 1$) as (3).

$$L_i = M_i \mod 3$$  \hspace{1cm} (2)

$$[C] = ([L], [P]) \mod m$$  \hspace{1cm} (3)

where

$[C]$: The encrypted matrix $3 \times 3$

Phase 2: The encrypted matrix $[C]$ of the previous stage was randomly hidden inside the magic square $[MS]$ of the $12 \times 12$ doubly even order. $[MS]$ was divided into 16 by sub-magic square $4 \times 4$. The encrypted matrix $[C]$ resulting from the previous stage is expanded to a $4 \times 4$ by randomly adding 8 numbers (salt) from 1 to 255 (polynomial numbers of GF ($2^8$)). Thereafter, the matrix $[C]$ was multiplied with one of the sub-magic squares $[A]$ (selected randomly) by the affine cipher function. Each element of the encryption matrix $C_i$ corresponds to one element in the sub-magic square $A_i$. The affine cipher as in (4) was applied, except one element that is left as a pointer. The result is a matrix $[E]$ $4 \times 4$ represents the final of cipher text.

$$E_i = (A_i \cdot C_i + b) \mod m$$  \hspace{1cm} (4)
The Encryption algorithm of proposed method as the following:

**Input**: block (9 bytes) of encoded original data  
**Output**: block (16 bytes) of cipher text

1. **Step 1** 
   Plain text [PO] was labeled using the ASCII code for coding the letters to polynomial numbers of GF ($2^8$) [P].  
   \[ [P]O \rightarrow [P] \]

2. **Step 2** 
   The key elements were arranged in an odd order 3x3 magic square [M]. Latin square [L] was derived from the magic square by taking modulo 3. by multiplying the 3x3 Latin square [L] and encoded matrix [P] with an irreducible polynomial (m)
   \[ L_i = M_i \mod 3 \]  
   \[ C = ([L] \cdot [P]) \mod m \]  
   \[ C \] Expands to a 4x4 by randomly adding 8 polynomial numbers of GF ($2^8$).  

3. **Step 3** 
   Magic square [MS] of the 12x12 doubly even order was constructed. [MS] divides into 16 by sub-magic square 4x4. The matrix [C] was multiplied with one of the sub-magic squares [A] (selected randomly) by the affine cipher function.
   \[ E_i = (A_i \cdot C_i + b) \mod m \]  

### 2.3. Decryption

The decryption process was executed by reversing the previous stages of the encryption process.

**Phase 1**: In this phase, the encryption matrix [C] was returned by (5), where uses the inverse of each element of the specific sub-matrix [A] multiply with final encryption matrix elements [E]. The sub-magic square [A] was selected using the element (pointer) into the matrix. Then, the encryption matrix [C] was reduced from 4x4 to 3x3 by eliminating the random numbers (salt).

\[ [C] = A_i^{-1}(E_i - b) \mod m \]  

**Phase 2**: This stage uses the inverse of 3x3 Latin squares [L$^{-1}$] and multiplied by the cipher matrix [C] to obtain the encoded plain text matrix [P] as in (6).

\[ [P] = ([L^{-1}], [C]) \mod m \]

**Phase 3**: Decoding the encoded plaintext matrix [P] to the plain text matrix 3x3 [PO] based on the positions of magic square elements [M].

\[ [P] \rightarrow [PO] \]

The Decryption algorithm of proposed method as the following:

**Input**: block (16 bytes) of cipher text  
**Output**: block (9 bytes) of plain text

1. **Step 1** 
   the inverse of each element of the specific sub-matrix [A] multiply with final encryption matrix elements [E].
   \[ [C] = A_i^{-1}(E_i - b) \mod m \]  

2. **Step 2** 
   the inverse of 3x3 Latin squares [L$^{-1}$] and multiplied by the cipher matrix [C] to obtain the encoded plain text matrix [P].
   \[ [P] = ([L^{-1}], [C]) \mod m \]

3. **Step 3** 
   Decoding the encoded plaintext matrix [P] to the plain text matrix 3x3 [PO] based on the positions of magic square elements [M].
   \[ [P] \rightarrow [PO] \]

**Example**

The message to be sent is assumed to be "Ciphering" and the key is a magic square “35, 37, 39, 41, 43, 45, 47, 49 and 51, the steps of the encryption process as the follows:

a) The message of the plain text is encoded using the ASCII code as a Figure 6.
b) One odd-order $3 \times 3$ magic square (M) is constructed for the permutation of the elements of the plain text based on the position of elements in (M), thereby obtaining the encoded matrix (P).

\[
\begin{array}{ccc}
\text{plaintext} & c & i & p & h & e & r & i & n & g \\
\text{cod} & 99 & 105 & 112 & 104 & 101 & 114 & 105 & 110 & 103 \\
\text{position} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9
\end{array}
\]

Figure 6. Encoding the message

\[
\begin{array}{cccc}
\text{Plaintext} & \text{position} & [M] & \text{Permutation} & \text{Encoded matrix} \ [P] \\
\text{c} & i & p & h & e & r & i & n & g & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 110 & 99 & 114 \\
\text{h} & e & r & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 112 & 101 & 165 \\
i & n & g & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 104 & 109 & 165
\end{array}
\]

\[
L_i = M_i \mod 3
\]  

(7)

\[
[C] = ([L].[P]) \mod m
\]  

(8)

d) The encrypted matrix is extended to $4 \times 4$ (C_x) by randomly adding 8 polynomial numbers of GF ($2^8$).

\[
\begin{array}{cccc}
\text{C_x} & 243 & 142 & 169 & 160 \\
231 & 160 & 191 & 187 \\
150 & 180 & 171 & 141 \\
12 & 7 & 122 & 199
\end{array}
\]

e) Building The Magic Square doubly even order $16 \times 16$ including 16 sub-square of even magic square is as in Figure 7.
f) By applying the affine cipher function on encryption matrix (C) and sub-square of the even 4×4 magic square \([A]\) selected randomly, the result represents the final encrypted matrix. The affine cipher function on each element of the encryption matrix is applied, except the element at the bottom of the left corner is substituted with an element at the bottom left corner in the sub-magic square to be a pointer, where (b) value is equal 180 as a constant in (9).

\[ E_i = (A_i, Cx_i + b) \mod m \]  

(9)

2.4. The decryption process uses two stages as follows:

g) The inverse of the affine cipher function on the encryption matrix (E) and the specific sub-inverse magic square affine cipher is applied as following in inverse (10):

\[ Cx = A^{-1}(E - b) \mod m \]  

(10)

h) The matrix is returned to 3×3 [c] and the random numbers (salt) that added at the encryption stage were deleted.
The inverse of the Latin square is used and multiplied with the $3 \times 3$ encryption matrix as following in (11).

$$P = ([L^{-1}]. [C]) \mod m$$  \hspace{1cm} (11)

3. RESULTS AND ANALYSIS

The proposed method provided the processing of a repetition problem in the ciphertext. The important characteristic of the encryption algorithm is the Avalanche Effect, where any single bit change in the plain text or key must be a more change in the bits of encrypted text. Avalanche effect test of the proposed method can be calculated by using (12). The test calculates the avalanche effect of the proposed method when changing 1-bit in the key and keeping plaintext constant and changing in plaintext by 1-bit and keeping the Key bits constant. In two cases, the number of bits that differ between the two cipher-texts is calculated by XOR operation. Then, Table 1 shows the avalanche effect of proposed method:

$$Avalanche\text{ Effect} = \frac{\text{Number of changing bits in the cipher text}}{\text{Number of bits in the cipher text}} \times 100\%$$  \hspace{1cm} (12)

| Sample No. | Keys | input | Output MDES | Avalanche test | Avalanche Test % |
|------------|------|-------|-------------|----------------|------------------|
| 1          | 49, 35, 45, 39, 43, 47, 41, 51, 37 | 99, 105, 112, 104, 101, 114, 105, 110, 103 | 71, 92, 236, 2, 141, 1, 107, 225, 60, 182, 238, 87, 227, 239, 174, 52 | 0.648 | 64.8 % |
| 2          | 49, 35, 45, 39, 171, 47, 41, 51, 37 | 99, 105, 112, 104, 101, 114, 105, 110, 103 | 255, 242, 24, 111, 282, 255, 158, 62, 210, 32, 161, 180, 250, 49, 251, 171 | 0.609 | 60.9 % |

Main percentage avalanche value 0.628  62%

$$Avalanche\text{ Effect Sample } 1 = \frac{4+5+5+4+7+6+7+4+4+5+5+6+4+6}{128} = 0.648$$

$$Avalanche\text{ Effect Sample } 2 = \frac{4+5+5+2+4+5+5+6+6+7+4+6+6+3}{128} = 0.609$$

The Avalanche Effect results of the proposed method indicate that the ratio of 62% is a good ratio, where the accepted ratio is 50% indicates the algorithm has perfect confusion and diffusion, as well as the ratio indicates that there is less repetition in the ciphertext. When the blocks of plain text are almost the same. This good ratio comes from that method when it is selected the sub-magic square randomly in each encryption process. The randomness tests are important for testing the cipher text to determine if there is any deviation or bias between plaintext/cipher text bits and to ensure the random form for the cipher text. The proposed technique provides accepted results based on the NIST randomness tests. Where a P-value for a test is equal to one, and then the value will be ideal randomness. A P-value of zero refers that the value is
completely non-random. The results tested are displayed in Table 2. The results of the randomness tests of the proposed method are acceptable for all the p-values of the statistical tests where all p-values are nearest from 1 that indicated the encrypted data are random text. Accordingly, that randomness results are acceptable and no frequency of all possible overlapping m-bit patterns across the entire sequence.

| Statistical Tests          | Input Size (n) | P-value Proposal method | The results |
|----------------------------|----------------|-------------------------|-------------|
| Frequency (monobit)        | 10000          | 0.873124                | Pass        |
| Test                       | 100000         | 0.624278                | Pass        |
| Average of P-value         |                | 0.748701                | Pass        |
| (n=8)                      | 10000          | 0.287645                | Pass        |
| Average of P-value         |                | 0.460955                | Pass        |
| Test m=3                   | 100000         | 0.955915                | Pass        |
| Average of P-value         |                | 0.916228                | Pass        |
| Linear Complexity          | 10000          | 0.447321                | Pass        |
| Test (M=100)               | 100000         | 0.505732                | Pass        |
| Average of P-value         |                | 0.476526                | Pass        |
| Runs Test                  | 100000         | 0.289120                | Pass        |
| Average of P-value         |                | 0.545164                | Pass        |
| Total Averages of P-value  |                | 0.629515                | Pass        |

4. CONCLUSION

The proposed technique process the problem of repetition in the ciphertext and increase the permutation of the plain text by uses the functionality of a 3x3 magic square and the diagonal Latin square. The proposed method demonstrated the ability to process repetition in encrypted data effectively when entering similar texts in each encryption process, in addition, the method demonstrated the high randomness of the encrypted texts. The proposed was achieved by uses a magic square 12x12 to hiding encrypted data and eliminates the repetition elements. Thus, the encrypted data are substantially secure and robust against attackers based on the tests the Avalanche Effect and randomness results that shown accepted results in the ciphertext. It is recommended that research is used in the field that corresponding database encryption because the database security system needs encryption methods that not suffer from the problem of repetition data.

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