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TESSERACT ENCRYPTION ALGORITHM USING LATIN SQUARE OF ORDER 8 (TEA-O8)

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Abstract: In this paper, we investigate the possibility of extending Latin Square of Order 4 in Hybrid Cube Encryption Algorithm (HiSea) and Three-Dimensional Hybrid Cubes Encryption (3D-HiSea) algorithm using Latin square of order 8. The objective of this research is to investigate the security improvement of key provided in current algorithm using Four-Dimensional (4D) concept. Entries of Latin square of order 8 are used as a method extended to form a 4D Hybrid Cubes or Tesseract (TEA-08). The existence of 108 quintillion LS of order 8 (LS8) open up new possibilities for increasing possible key space for 3D-HiSea. New tesseract structure based on 8 3D-Hybrid Cube has been successfully implemented using LS order 8. Master Key generated from HiSea, 3D HiSea and Tesseract is used to study its security analysis using Entropy Test. Next, Frequency, Block Frequency and Run Test analysis is perform using NIST Testing Tool to investigate the security of ciphertext produced. The results show that entropy for TEA-08 master key is 0.9961 more closer to 1. Furthermore, ciphertext security analysis resultant the P-Value of Frequency is 0.328363, Block Frequency is 0.488475 and Run Test is 0.457713 which greater than 0.01 prove that algorithm proposed are random. Thus, based on the findings TEA-O8 it can be concluded that the key and ciphertext generated is random and can be evaluated further to include other security analysis testing tool and method which suitable for non-binary block cipher.

Keywords:Latin Square of Order 8; Tesseract; 3D-Hybrid Cubes; HiSea; KSA.

I. INTRODUCTION

Ininformation security, protecting the secrecy, integrity and availability of the data confidentiality is critical to prevent access from unauthorized parties because data is always evolving [1, 2]. Cryptography is a process to covert data (plaintext) into an unreadable message (ciphertext) or also known as secret writing. Example of cryptographic algorithms are Rijndael, Twofish, Triple-DES, TOY100, HiSea, 3D-HiSea Cryptanalysis, on the other hand is a method of breaking ciphertext created by cryptographic algorithm and sometimes used to evaluate the strength[3, 4]. Some methods or tools for performing cryptanalysis are Dieherd, NIST Evaluation Criteria, DAV-Sexton, Entropy, Avalanche Effect, Correlation Assessment, ciphertext attack, known plaintext attack and many more. The purpose of this research is to provide alternative techique for increasing key space for non-binary block cipher**.** Based on the classification of key for cryptographic algorithm in Figure 1, this research focus on non-binary algorithm.

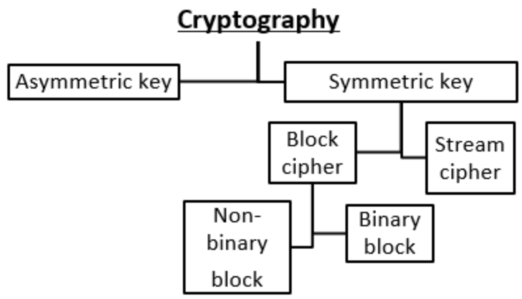

Figure 1: The classification key used in cryptography

The standard bit size for binary block cipher are 64, 128, 192 and 256 whereas the non-binary block cipher has no standardize of bit and depends on the cipher implementation [5]. The idea in this paper is to enhance the key space using latin square order 8 as an improvement from the previous HiSea [6] and 3D HiSea [7] algorithms. The properties of various order of Latin square which offer many possible permutation have been used in many application. Application of Latin Square of order 9 (Soduku) also used to provide a systematic redudancy in the implementation of watermarking for digital images [8]. In [6] permutation of {1,2,3,4}are used to generate 576 Latin square of order 4,then it is used to generate Orthogonal Latin squares, magic square, magic cubes and hybrid cubes in the implementation of HiSea. Mushtaq et al.,[9, 10] introduce 3D-HiSea using Triagular Cordinate Extraction (TCE) and Key Schedule Algorithm using Hybrid Cubes (KSAHC).

II. RELATED WORKS

All related works to construct algorithm of TEA-O8 is discussed in this section.

A. Permutations and Combinations using Latin Square in Cryptography

Table 1 shows all possible number of Latin squares based on permutation of order *n*.

Table 1: Possible Permutation of $n_i \ x \ n_j$ Latin Squares ($1 \leq i,j \leq n$)

R_n	**The Number of $n_{i,j}$**
1	1
2	2
3	12
4	576
5	161,280
6	812,851,200
7	61,479,419,904,000
8	108,776,032,459,082,956,800

Ren et al. [11]stated that there are 108,776,032,459,082, 956,800 of permutation set can be produce for Latin square order 8. The usage of Latin Square of Order 8 can be explored further to be used in implementing cryptographic system.

B. Hybrid Cubes Encryption Algorithm (HiSea)

HiSea is a non-binary block cipher that used Latin Square of order 4 as one of its elements to generate Orthogonal Latin Square, Magic Cubes and Hybrid Cubes [12].Various faces of hybrid cube are used to generate encryption key for the encryption algorithm. Figure 2 is the framework overview of HiSea.

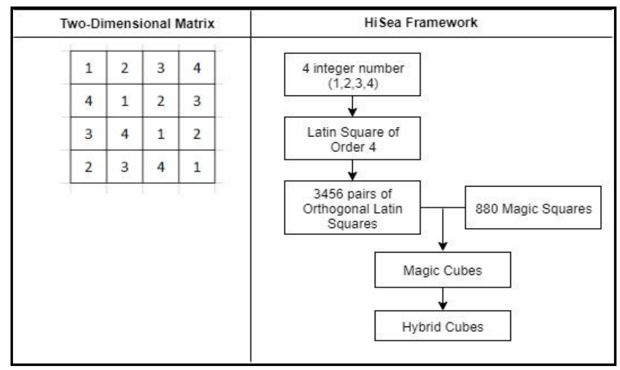

Figure 2: An Overview of HiSea framework and 2D matrix representation

Based on the framework overview, HiSea algorithm is 2-Dimensional algorithm which not strong enough to prevent the attack. The encryption process is represented in 2D is weak against attack [13].

C. Three-Dimensional Hybrid Cubes (3D-HiSea)

In 2017, Mushtaq et al., [9] proposed a new technique called Triangular Coordinate Extraction (TCE) that create more permutation of values based on face values of hybrid cube. to improve the algorithm HiSea. Rotation of Hybrid Cubes from various angle create a Three-Dimensional (3D) Hybrid Cubes [10]. The improvement has been made using 3-Dimensional concept. HiSea is used as one of its important elements which combine selection of layers HiSea to construct the cube using TCE technique. The purpose of improving Latin Square Order is to provide as many possible sets of Latin Square so we can provide a large key space for key selection to form a matrix in current algorithm. Through the 3D HiSea algorithm proposed, randomly selection of matrices from Latin Square order 4 is execute to form different layer of face for generating a single cube. The purposed of using large key space is to slower the work of attacker and prevent prediction to retrieve key used for encryption and decryption process [7]. Figure 3 is a Cube shape of 3D matrix which is selected as an idea to improve previous algorithm of two-dimensional concept before the rotation process take an action.

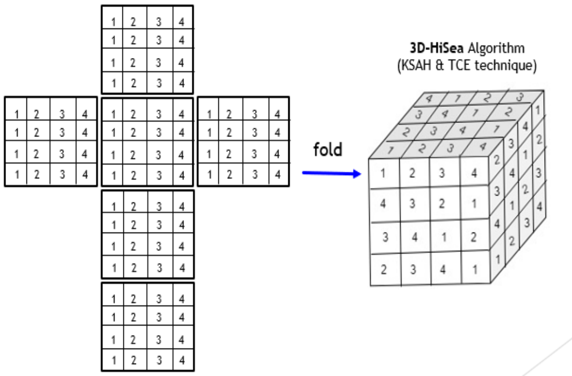

Figure 3:Formation of a single Cube matrices from combination of 2D matrix

By using Cube concept, six faces of 2D matrices were generated. Thus, HiSea algorithm is used as one of its important elements which combine selection of layers HiSea to construct the cube using TCE technique. The purpose of improving Latin Square Order is to provide as many possible sets of Latin Square so we can provide a large key space for key selection to form a matrix in current algorithm. Through the 3D HiSea algorithm proposed, randomly selection of matrices from Latin Square order 4 is execute to form different layer of face for generating a single cube. The purposed of using large key space is to slower the work of attacker and prevent prediction to retrieve key used for encryption and decryption process.

D. Latin Square in Others Cryptographic Algorithm Design

Latin square is widely used in cryptography area not just in HiSea and 3D-HiSea algorithm. Table 2 shows the needs of Latin square in helping to design a secure cryptographic algorithm.

Table 2: Latin square concept in others cryptographic algorithm design.

Ref.	Title	Latin Square Order	Descriptions
[14]	Design of Strong Cryptographic Schemes Based on Latin Squares	4 and 5	Latin square help to design of strong and efficient cryptographic algorithm of ciphering and decipher schemes.
[15]	A New Cryptographic Hash Function Based on Latin Squares and Non-Linear Transformations	3	Strength of cryptographic hash using Latin squares, complex shift and non-linear transformations operations increases at a low computational overhead.
[16]	A Novel Latin Square Image Cipher	256	The generation of Latin square from 256-bit key (256 x 256 LS) for encryption and decryption can resist attack such as brute force and can be expend more bigger size in the future.

Based on Table 2 shows that the technique of using Latin Square concept in cryptography design is not a new proposition and it is as one of the efficient ways to enhance the algorithm security.

III. METHODS

Latin Square of order n is filled with matrix of n^2 where its element occurs only once in a single row and column, and all the element must be integers between 1 and n [17]. The generation of all possible set is based on the following definition:

Definition 1 [18]A Latin Square Order *n* is donated as

$$R_n = [r(i,j) : 1 \le i, j \le n] \quad (1)$$

is a two dimensional (*nxn*) square matrix such that every row and column is a permutation of set of number natural number {1,..., *n*} and without repetition. Based on Definition 1, Latin square of order 8 consists of eight rows which have distinct combination from the set {1,2,3,4,5,6,7,8}. Therefore, the number of different ways to order eight numbers is 8! or 40,320. Latin square of order 8 are generated using series of combination and permutation of {1,2,3,4,5,6,7,8} as described in the following steps:

a) Generate all possible combination of {1, 2, 3, …, 40320} with 8 elements which are used as an index for selecting possible sequence for generating Latin squares of order 8. This combination, $\binom{40320}{8}$ will generate 17311793 x 10^{25} possible combinations of rows which have values from the set {1, 2, 3, …, 40320}.
b) Generate permutation of the set {1,2,3,4,5,6,7,8}. This permutation is then used to build entries for constructing Latin square of order 8.
c) Generate permutation for each entry in step (a) and used this as an index to select and sort entry based on columns in step (b). This step will generate all possible combination of 8-by-8 matrices.
d) Select only matrices where intersection between all rows and columns with standard set {1,2,3,4,5,6,7,8} will result in unique matrix with entries values of all 8's. This unique characteristic of Latin square as in Definition 3.1 is used to select Latin square in our implementation.
e) This method will generate 108,776,032,459,082,956, 800 Latin square of order 8 which can be used to generate possible Tesseract based on 3D-Hybrid Cubes[11].

Two examples of Latin Square of Order 8 is shown in the Figure 4.

$$\text{Set 1:}\quad \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 2 & 3 & 4 & 5 & 6 & 7 & 8 & 1 \\ 3 & 4 & 5 & 6 & 7 & 8 & 1 & 2 \\ 4 & 5 & 6 & 7 & 8 & 1 & 2 & 3 \\ 5 & 6 & 7 & 8 & 1 & 2 & 3 & 4 \\ 6 & 7 & 8 & 1 & 2 & 3 & 4 & 5 \\ 7 & 8 & 1 & 2 & 3 & 4 & 5 & 6 \\ 8 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \end{bmatrix}$$

$$\text{Set 2:}\quad \begin{bmatrix} 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 \\ 7 & 6 & 5 & 4 & 3 & 2 & 1 & 8 \\ 6 & 5 & 4 & 3 & 2 & 1 & 8 & 7 \\ 5 & 4 & 3 & 2 & 1 & 8 & 7 & 6 \\ 4 & 3 & 2 & 1 & 8 & 7 & 6 & 5 \\ 3 & 2 & 1 & 8 & 7 & 6 & 5 & 4 \\ 2 & 1 & 8 & 7 & 6 & 5 & 4 & 3 \\ 1 & 8 & 7 & 6 & 5 & 4 & 3 & 2 \end{bmatrix}$$

Figure 4: Two Latin Squares of order 8.

Each row in Latin square of order 8 can be used to represent one of the 3D-Hybrid Cube in the Tesseract.

A. Tesseract Encryption Algorithm using Latin Square of Order 8 (TEA-O8).

Using Tesseract concept, we can increase the use of complex mixing row and column performance. Constant [19] stated that four dimensions depend on our imagination as we need to deal with a complex concept also known as hypercube: higher level of a cube. Another interesting form of 4D can be found from different perspective in geometry studies called as 4D polytopes. Among 4D polytopes such as hypercube also known as Tesseract [20, 21], Octaplex[22] and cross-polytope;16- cell [21] is generated from its hyperplane either from basic shape of square or rectangle.

B. Framework Design for TEA-08

In this paper, we choose Tesseract as our framework to extend the existing 3D-Hybrid cubes because the process will increase the number of key spaces for a new key schedule algorithm. Figure 5 shows the framework of 3D-HiSea algorithm which is extended using proposed algorithm as highlighted in color orange.

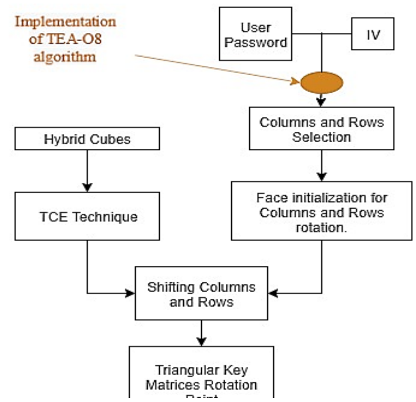

Figure 5:3D-HiSea algorithm framework

The algorithm framework for TEA-O8 is designed as in Figure 6.

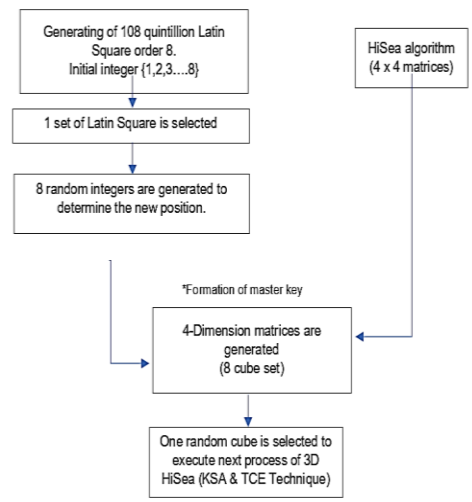

Figure 6: Framework Design for TEA-O8

Base on Figure 6, the possible permutation of all Latin square order 8 is generate and is used as our container for new matrix selection of new key schedule within the process of encryption. Using the set permutation of 108 Quintillion we will select only one of the sets to produce new technique as improvement of 3D HiSea. 3D HiSea improvement involved with the dimensional which have strong related with the coordinate geometric. The geometric concept is used to identify the position of each index for element selection. Six matrices from set permutation 576 is select to form a Face 1, Face 2, Face 3, Face 4, Face 5 and Face 6. Figure 7 shows the coordinated represent after row and column selection.

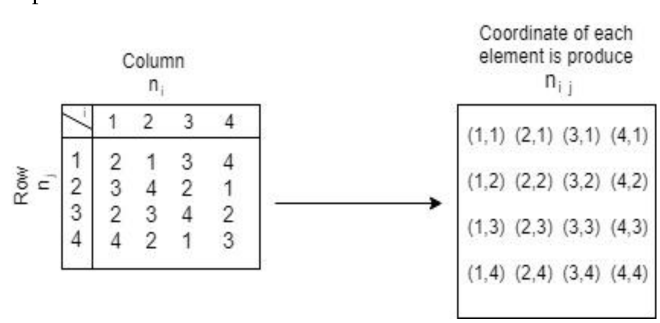

Figure 7: Coordinate that represent the element after selection

Coordinate of each element will be recorded in a matrix form where row and column are representing as (column, row) for *i* and *j*. After that the third attribute will be added as a present of faces within the selection such as (faces, column, row). This research studies are to discuss the method improvement of 3D HiSea based on Latin Square within the higher dimensional concept. Eight cubes are needed to generate a single 4-Dimensional Cube or Hypercube. Figure 8 outline the theoretical construction of 4-Dimensional HiSea Algorithm using Latin Square Order 8.

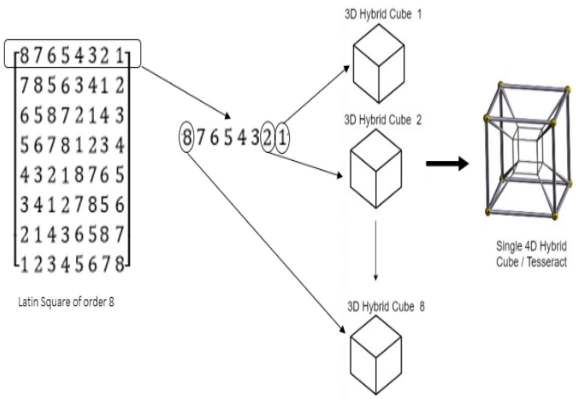

Figure 8: Construction of 4D Hybrid Cube Using Latin Square of Order 8.

From all set of Latin Square Order 8 already produce, one set 8 by 8 matrix will be chosen randomly. Next, from one selected set we will choose one random row to re-arrange the position of cube to produce an eight cube to construct a single Four-Dimensional(4D) matrices of HiSea. These 4D metrices will be used as our new master key for encryption and decryption process. An earlier stage of implementing had been made to execute the concept of Latin Square Order 8 in 3D HiSea to produce the extended algorithm for construct our Four-Dimensional(4D) Hybrid Cube Encryption Algorithm.

Process of TEA-O8: The main component needed to construct Tesseract algorithm such as all possible set permutation LS order 8 and Hybrid Cube Layer. 108 Quintillion of LS order 8 is prepared using Latin Square generator tool implement by [23]. Following text and password is used to demonstrated the algorithm:

- Plaintext: *4D-HiSea (Tesseract) is the extended of 3D HiSea Algorithm UTHM*.
- Password (Key): *4342343252*

Plaintext insert by user is a message to be encrypt and password as an initial key to generate master key and will be used during ciphering process. The plaintext is converted into ASCII codes that will produce matrix 4 by 4 of 64 decimals for 64 characters input as shows in the following matrix:

$$Matrix1=\begin{bmatrix}52&68&45&72\\105&83&101&97\\40&84&101&115\\115&101&114&97\end{bmatrix}$$

$$Matrix2=\begin{bmatrix}99&116&41&32\\105&115&32&116\\104&101&32&101\\120&116&101&110\end{bmatrix}$$

$$Matrix3=\begin{bmatrix}100&101&100&32\\111&102&32&51\\68&32&72&105\\83&101&97&32\end{bmatrix}$$

$$Matrix4=\begin{bmatrix}65&108&103&111\\114&105&116&104\\109&44&32&85\\84&72&77&46\end{bmatrix}$$

Steps of algorithm proposed is shown in following example:

a. Eight group(cube) matrices are generate using HiSea [12] with the initial position {1,2,3,4,5,6,7,8}.
b. One set of Latin Square is selected randomly from 108 Quintillion. Example set selected as follows:

A set of Latin Square order 8

$$=\begin{bmatrix}5&6&8&7&1&4&2&3\\4&5&7&6&8&3&1&2\\3&4&6&5&7&2&8&1\\2&3&5&4&6&1&7&8\\1&2&4&3&5&8&6&7\\8&1&3&2&4&7&5&6\\7&8&2&1&3&6&4&5\\6&7&1&8&2&5&3&4\end{bmatrix}$$

Each row has unique list value that has no duplicate entries from another row.

c. From one set selection, one random row is selected to re-arrange the value of a cubes.
d. For example, row number 6 is selected from LS. The position of value contain will be re-arranging according to the new list generate such as in Figure 9:

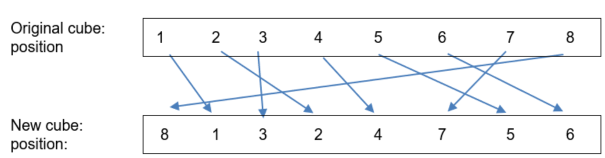

Figure 9: Re-arrange cube using algorithm proposed

Figure 10 is the overview of new matrix in Four-Dimensional concept using Latin Square Order 8 position.

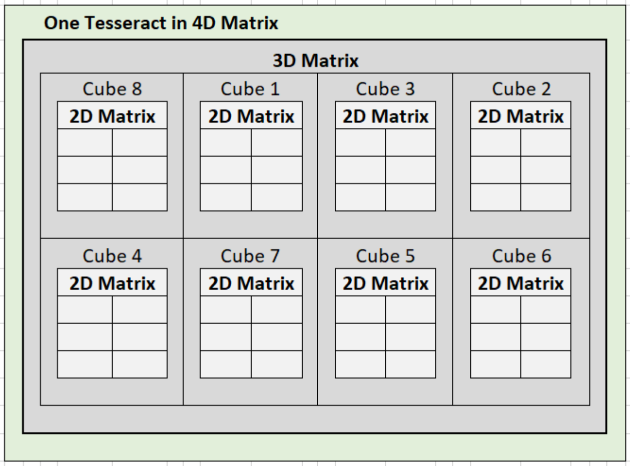

Figure 10: Construction of 4 Dimensional Matrices

e. From new list of cubic position only one cube is selected randomly to generate new master key. For example, cube number 6 from original position is selected which actually consist cube number 7. Position of Eight Cubes is re-arranged as mention in this steps c.

f. Finally, new master key produced is used to process encryption and decryption is execute to generate the ciphertext.

IV. Results and Analysis

The security analysis of TEA-O8 is perform based on Entropy, NIST Testing Tool and pseudo random test to evaluate the performance against 3D-HiSea.

A. *Entropy Evaluation.*

An entropy has more than one bit for every output consider as low entropy. Entropy technique is used to measure the order movement. The relationship between encryption key and ciphertext of order 4 by 4 matrix is calculate using Shannon's entropy to perform the entropy test formula for keys, message and ciphertext. Each value entries are divided with sum of all value of total entries to get the normalization of all entry so that the value lies between 1 and 0. Table 3 shows the master key comparison of entropy test between TEA-O8 with the previous algorithm.

Table 3: Master Key Entropy Test for current and previous algorithm

Algorithm Name	Latin Square Order, $L(n)$	Entropy
HiSea	4	0.8303
3D-HiSea	4	0.8972
TEA-O8	8	0.9961

The result proves that increasing of Latin square order to generate Master key will affect a good entropy result. By using permutation of Latin Square Order 8 Entropy is also tested as in Table 4:

Table 4: Entropy Test of overall TEA-O8 algorithm

Proposed algorithm entropy	
Initial Matrix (IM)	0.9682
Session Keys	0.9428
Master Key	0.9961
Ciphertext 1	0.9993
Ciphertext 2	0.9987
Ciphertext 3	0.9993
Ciphertext 4	0.9987
Average Ciphertext (1-4)	**0.9990**

Based on the Table 4 of security analyst using Entropy test shows that the IM entropy is 0.9682, Session key is 0.9428, Master key generate is 0.9961 and Average of ciphertext is 0.999 resultant a good characteristic of entropy closer to 1.

B. *National Institute of Standards and Technology (NIST) Testing Tool.*

Among randomness test used in cryptography is NIST suit test. It has a 15 classification of test in order to execute different criteria of randomness [24]. This test is used to analyse ciphertext produced using algorithm proposed. Whenever P-value is greater than 0.01 it is considering the algorithm proposed already pass NIST test [25]. Frequency, Block Frequency and Run Test were evaluated during test perform. Therefore, the proposed algorithm is tasted as follows in Table 5, Table 6 and Table 7.

Table 5: Ciphertext Frequency test analysis

Key Test ID	Frequency
S1_K1	0.4419
S1_K2	0.2299
S1_K3	0.0887
S1_K4	0.0164
S2_K1	0.9000
S2_K2	0.0396
S2_K3	0.3035
S2_K4	0.6069
Average	***0.328363***

Table 6: Ciphertext Block Frequency test analysis

Key Test ID	Block Frequency
S1_K1	0.4887
S1_K2	0.7021
S1_K3	0.4210
S1_K4	0.1194
S2_K1	0.6671
S2_K2	0.5238
S2_K3	0.7362
S2_K4	0.2495
Average	***0.488475***

Table 7: Ciphertext Runs test analysis

Key Test ID	Runs Test
S1_K1	0.5148
S1_K2	0.7655
S1_K3	0.4391
S1_K4	0.7045
S2_K1	0.4927
S2_K2	0.1065
S2_K3	0.5486
S2_K4	0.0900
Average	***0.457713***

Based on average Frequency is 0.340863, Block Frequency 0.488475 and Runs Test is 0.457713 show that the P-value result is greater than 0.01. Thus, it can be concluded that the sequence of algorithm proposed are random.

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