International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** I **Month of publication:** January 2022

DOI: https://doi.org/10.22214/ijraset.2022.40138

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue I Jan 2022- Available at www.ijraset.com

Cryptographic Algorithm Based on Prime Assignment

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Abstract: Cryptography is a concept of protecting information and conversations which are transmitted through a public source, so that the send and receiver only read and process it. There are several encryption and decryption algorithm which involves mathematical concepts to provide more security to the text which has to be shared through a medium. In this paper, an algorithm is provided for both coding and decoding using cyclic symmetric matrices. Also Euler totient function, prime numbers are employed here. Furthermore, algorithm using prime number in integers is extended to prime numbers in Gaussian integers. This concept increases the security of the text.
Keywords: Cryptography; encryption- decryption algorithms; Gaussian primes; cyclic symmetric matrix. 2010 MSC Subject Classifications - 11T71, 11C20, 11A25, 11R04.

I. INTRODUCTION

For centuries, people have sent secret messages by various means. But some messages were not maintained secretly as there was no proper security. In order to maintain secrecy, cryptography was developed. It is the process of converting ordinary plain text (message to be sent) into some unintelligible text and vice versa. It helps to transmit data in a particular form so that the intended persons can read and process it. It is also useful for user authentication.

In olden days, an algorithm in cryptography was based on concepts which are well- known by all. But now- a- days, it is mainly based on mathematical theory and computer applications. Especially, number theory is playing a vital role in it, which employs the concepts such as congruence, Euler's theorem.

In modern days, one can make use of any mathematical concepts to make their algorithm. As much as mathematics imposed, as much as security increases. Motivated by [3], this work aims to propose an algorithm to improve the security based on things such as prime numbers, Euler phi function, cyclic symmetric matrices. By modifying the assignments of alphabets in [3], this work is developed.

This paper involves two algorithms. First one uses integer prime assignment whereas second one uses Gaussian prime assignment. For the second case, Euler phi function on Gaussian integers $\varphi_{\mathbb{Z}[i]}$ is employed.

Common notations and definitions:

1) $W_i = i^{th}$ word in the message to be sent

2) $\eta(W_i)$ = no. of letters in W_i

3) $$E(\eta(W_i)) = \begin{cases} k_i = \frac{\eta(W_i)+1}{2}, if\ \eta(W_i)\ is\ odd \\ k_i = \frac{\eta(W_i)}{2}, \quad if\ \eta(W_i) is\ even \end{cases}$$

4) I_i = Identity matrix of order i

5) $A_i = k_i^{th}$ row of cyclic matrix M_i

6) $D(A_i)$ = diagonal matrix with values in A_i

II. ALGORITHM BASED ON INTEGER PRIMES

A. *Euler phi Function on* $\mathbb{N}$

1. Euler phi function $\varphi(n)$ is defined on natural numbers which counts the numbers which are less than n and prime to it. ie.,$\varphi(n) = |\{k \in \mathbb{N}: k < n \text{ and } (k,n) = 1\}|$
2. For a prime p, $\varphi(p) = p - 1$

B. *Algorithm for Encryption*

Assign the first 26 prime numbers to the alphabets. i.e.,

2	3	5	7	11	13	17	19	23	29	31	37	41
A	B	C	D	E	F	G	H	I	J	K	L	M
N	O	P	Q	R	S	T	U	V	W	X	Y	Z
43	47	53	59	61	67	71	73	79	83	89	97	101

The algorithm is defined as follows:

1) Let the message to be encrypted be $W_1, W_2, \ldots, W_n$ (separated as words and omitting spaces).
2) For all $1 \le i \le n$, assign each letters in W_i with the above defined table.
3) Apply φ for each assigned values in W_i.
4) Construct a cyclic symmetric matrix for each W_i separately.
5) Calculate $E\big(\eta(W_i)\big)$, for all $1 \le i \le n$
6) Find the k_i^{th} row from the matrix and construct $A_i, 1 \le i \le n$
7) Evaluate $D(A_i) - \eta(W_i) I_{\eta(W_i)}, 1 \le i \le n$, which is the encrypted key. (For each word it is separated by commas)

C. *Algorithm for Decryption*

1) Let $B_i = D(A_i) - \eta(W_i) I_{\eta(W_i)}, 1 \le i \le n$
2) Calculate $C_i = D(B_i) + \eta(B_i) I_{\eta(B_i)}, 1 \le i \le n$
3) Find $E\big(\eta(B_i)\big) = k_i, 1 \le i \le n$

This gives that first digit of C_i is the k_i^{th} letter of the i^{th} word.
Now, the second digit of C_i is the $(k_i + 1)^{th}$ letter of i^{th} word and so on (This works on cyclic order).

4) Rewrite C_i as in the above order.
5) For every digit in C_i, add 1.
6) Convert the digits into alphabets.

a) *Example 1:* Let us work on the word "HELLO"

- *Encryption*
  - Let W_1 be the word $HELLO$
  - Assign the positions of the letters.

H	E	L	L	O
19	11	37	37	47

  - Apply φ

H	E	L	L	O
18	10	36	36	46

  - The cyclic symmetric matrix is

$$M = \begin{pmatrix} 18 & 10 & 36 & 36 & 46 \\ 10 & 36 & 36 & 46 & 18 \\ 36 & 36 & 46 & 18 & 10 \\ 36 & 46 & 18 & 10 & 36 \\ 46 & 18 & 10 & 36 & 36 \end{pmatrix}$$

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- Here $\eta(W_1) = 5$, which is odd.

  Thus, $E(\eta(W_1)) = k_1 = \frac{5+1}{2} = 3$
- The 3^{rd} row of M forms A_1.

  i.e.,$A_1 = (36\ 36\ 46\ 18\ 10)$
- $$D(A_1) - \eta(W_1) I_{\eta(W_1)} = \begin{pmatrix} 36 & 0 & 0 & 0 & 0 \\ 0 & 36 & 0 & 0 & 0 \\ 0 & 0 & 46 & 0 & 0 \\ 0 & 0 & 0 & 18 & 0 \\ 0 & 0 & 0 & 0 & 10 \end{pmatrix} - \begin{pmatrix} 5 & 0 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 \\ 0 & 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 & 5 \end{pmatrix}$$
  $$= \begin{pmatrix} 31 & 0 & 0 & 0 & 0 \\ 0 & 31 & 0 & 0 & 0 \\ 0 & 0 & 41 & 0 & 0 \\ 0 & 0 & 0 & 13 & 0 \\ 0 & 0 & 0 & 0 & 5 \end{pmatrix}$$

  The encrypted key is 31 31 41 13 5.

- *Decryption*
- $B_1 = D(A_1) - \eta(W_1) I_{\eta(W_1)}$

  $= (31\ 31\ 41\ 13\ 5)$
- $C_1 = D(B_1) + \eta(B_1) I_{\eta(B_1)}$

  $= (36\ 36\ 46\ 18\ 10)$
- $E(\eta(B_1)) = \frac{5+1}{2} = 3$

  So first digit of C_1 is the 3^{rd} letter in W_1.

  The order is

36	36	46	18	10
3^{rd}	4^{th}	5^{th}	1^{st}	2^{nd}

- Thus the rewritten form is $(18\ 10\ 36\ 36\ 46)$
- Adding 1, one can get $(19\ 11\ 37\ 37\ 47)$, which corresponds to the word "HELLO".

b) *Example 2:* Let us consider "WORK HARD"

- *Encryption*
- Let W_1 be the word $WORK$ and W_2 be $HARD$
- Assign the positions of the letters.

W	O	R	K
83	47	61	31

H	A	R	D
19	2	61	7

- Apply φ

W	O	R	K
82	46	60	30

H	A	R	D
18	1	60	6

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- The cyclic symmetric matrix is

$$M_1 = \begin{pmatrix} 82 & 46 & 60 & 30 \\ 46 & 60 & 30 & 82 \\ 60 & 30 & 82 & 46 \\ 30 & 82 & 46 & 60 \end{pmatrix} \text{and} M_2 = \begin{pmatrix} 18 & 1 & 60 & 6 \\ 1 & 60 & 6 & 18 \\ 60 & 6 & 18 & 1 \\ 6 & 18 & 1 & 60 \end{pmatrix}$$

- Here $\eta(W_1) = \eta(W_2) = 4$, which is even.

  Thus, $E(\eta(W_1)) = E(\eta(W_2)) = k_1 = k_2 = \frac{4}{2} = 2$

- The 2^{nd} row of M_1 forms A_1 and 2^{nd} row of M_2forms A_2.

  i.e., $A_1 = (46\ 60\ 30\ 82)$ and $A_2 = (1\ 60\ 6\ 18)$

- $$D(A_1) - \eta(W_1)I_{\eta(W_1)} = \begin{pmatrix} 46 & 0 & 0 & 0 \\ 0 & 60 & 0 & 0 \\ 0 & 0 & 30 & 0 \\ 0 & 0 & 0 & 82 \end{pmatrix} - \begin{pmatrix} 4 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 \\ 0 & 0 & 4 & 0 \\ 0 & 0 & 0 & 4 \end{pmatrix}$$

$$= \begin{pmatrix} 42 & 0 & 0 & 0 \\ 0 & 56 & 0 & 0 \\ 0 & 0 & 26 & 0 \\ 0 & 0 & 0 & 78 \end{pmatrix}$$

$$D(A_2) - \eta(W_2)I_{\eta(W_2)} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 60 & 0 & 0 \\ 0 & 0 & 6 & 0 \\ 0 & 0 & 0 & 18 \end{pmatrix} - \begin{pmatrix} 4 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 \\ 0 & 0 & 4 & 0 \\ 0 & 0 & 0 & 4 \end{pmatrix}$$

$$= \begin{pmatrix} -3 & 0 & 0 & 0 \\ 0 & 56 & 0 & 0 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 14 \end{pmatrix}$$

The encrypted key is $42\ 56\ 26\ 78, -3\ 56\ 2\ 14$.

- *Decryption*

- $B_1 = D(A_1) - \eta(W_1)I_{\eta(W_1)}$

$$= (42\ 56\ 26\ 78)$$

$$B_2 = D(A_2) - \eta(W_2)I_{\eta(W_2)} = (-3\ 56\ 2\ 14)$$

- $C_1 = D(B_1) + \eta(B_1)I_{\eta(B_1)}$

$$= (46\ 60\ 30\ 82)$$

$$C_2 = D(B_2) + \eta(B_2)I_{\eta(B_2)}$$

$$= (1\ 60\ 6\ 18)$$

- $E(\eta(B_1)) = E(\eta(B_2)) = \frac{4}{2} = 2$

  So first digit of C_1 is the 2^{nd} letter in W_1 and first digit of C_2 is 2^{nd} letter in W_2.

  The order is

46	60	30	82
2^{nd}	3^{rd}	4^{th}	1^{st}

1	60	6	18
2^{nd}	3^{rd}	4^{th}	1^{st}

- Thus the rewritten form is $(82\ 46\ 60\ 30)$ and $(18\ 1\ 60\ 6)$
- Adding 1, one can get $(83\ 47\ 61\ 31)$ and $(19\ 2\ 61\ 7)$, which corresponds to the words “WORK” and “HARD”

III. ALGORITHM BASED ON GAUSSIAN PRIMES

A. Gaussian Integers

Gaussian integers are complex numbers $z = a + ib$ where a, b are integers and it is denoted by $\mathbb{Z}[i]$. The norm of $z = a + ib$ is given by $N(a + ib) = a^2 + b^2$.

B. Gaussian Primes

$z = a + ib$is a Gaussian prime if one of the following holds:

- If $a \neq 0, b \neq 0$, then $a + ib$ is a Gaussian prime if and only if $N(a + ib) = a^2 + b^2$ is an integer prime.
- If $a \neq 0$, then bi is a Gaussian prime if $|b|$ is an integer prime and $|b| \equiv 3(mod\ 4)$.
- If $b \neq 0$, then a is a Gaussian prime if $|a|$ is an integer prime and $|a| \equiv 3(mod\ 4)$.

Note

If p is an integer prime such that $p \equiv 1(mod\ 4)$, then $p = x^2 + y^2$. Thus $x + iy, x < y$ is a Gaussian prime corresponding to p.

Euler phi function on $\mathbb{Z}[i]$

- In [1], $\varphi_{\mathbb{Z}[i]}(a + ib)$ is defined as the number of Gaussian integers which are invertible modulo $a + ib$.
- If $p + qi$ is a Gaussian prime, then $\varphi_{\mathbb{Z}[i]}(p + qi) = N(p + qi) - 1 = p^2 + q^2 - 1$

Algorithm for encryption.

Assign the Gaussian prime numbers to the alphabets. i.e.,

$1 + i$	$3 + 0i$	$1 + 2i$	$7 + 0i$	$11 + 0i$	$2 + 3i$
A	B	C	D	E	F
$1 + 4i$	$19 + 0i$	$23 + 0i$	$2 + 5i$	$31 + 0i$	$1 + 6i$
G	H	I	J	K	L
$4 + 5i$	$43 + 0i$	$47 + 0i$	$2 + 7i$	$59 + 0i$	$5 + 6i$
M	N	O	P	Q	R
$67 + 0i$	$71 + 0i$	$3 + 8i$	$79 + 0i$	$83 + 0i$	$5 + 8i$
S	T	U	V	W	X
$4 + 9i$	$1 + 10i$				
Y	Z				

The algorithm is defined as follows:

1) Let the message to be encrypted be $W_1, W_2, \ldots, W_n$ (separated as words and omitting spaces).
2) For all $1 \leq i \leq n$, assign each letters in W_i with the above defined table.
3) Apply $\varphi_{\mathbb{Z}[i]}$ for each assigned values in W_i.
4) Construct a cyclic symmetric matrix for each W_i separately.
5) Calculate $E(\eta(W_i))$, for all $1 \leq i \leq n$
6) Find the k_i^{th} row from the matrix and construct $A_i, 1 \leq i \leq n$
7) Evaluate $D(A_i) - \eta(W_i) I_{\eta(W_i)}, 1 \leq i \leq n$, which is the encrypted key. (For each word it is separated by commas)

Algorithm for decryption

a) Let $B_i = D(A_i) - \eta(W_i) I_{\eta(W_i)}, 1 \leq i \leq n$
b) Calculate $C_i = D(B_i) + \eta(B_i) I_{\eta(B_i)}, 1 \leq i \leq n$
c) Find $E(\eta(B_i)) = k_i, 1 \leq i \leq n$

   This gives that first digit of C_i is the k_i^{th} letter of the i^{th} word.

   Now, the second digit of C_i is the $(k_i + 1)^{th}$ letter of i^{th} word and so on (This works on cyclic order).
d) Rewrite C_i as in the above order.
e) For every digit in C_i, add1 and then observethat the remaining is in the form $x^2 + y^2$ so write it as $x + iy$ where $0 < x < y$ and if $y = 0$, write it as $x + 0i$.
f) Convert the digits into alphabets.

Example 3

Let us consider "WORK HARD"

- *Encryption*
- Let W_1 be the word $WORK$ and W_2 be $HARD$
- Assign the positions of the letters.

W	O	R	K
$83+0i$	$47+0i$	$5+6i$	$31+0i$

H	A	R	D
$19+0i$	$1+i$	$5+6i$	$7+0i$

- Apply $\varphi_{\mathbb{Z}[i]}$

W	O	R	K
6888	2208	60	960

H	A	R	D
360	1	60	48

- The cyclic symmetric matrix is

$$M_1 = \begin{pmatrix} 6888 & 2208 & 60 & 960 \\ 2208 & 60 & 960 & 6888 \\ 60 & 960 & 6888 & 2208 \\ 960 & 6888 & 2208 & 60 \end{pmatrix} \text{and} M_2 = \begin{pmatrix} 360 & 1 & 60 & 48 \\ 1 & 60 & 48 & 360 \\ 60 & 48 & 360 & 1 \\ 48 & 360 & 1 & 60 \end{pmatrix}$$

- Here $\eta(W_1) = \eta(W_2) = 4$, which is even.

  Thus, $E(\eta(W_1)) = E(\eta(W_2)) = k_1 = k_2 = \frac{4}{2} = 2$

- The 2^{nd} row of M_1 forms A_1 and 2^{nd} row of M_2 forms A_2.

  i.e., $A_1 = (2208 \quad 60 \quad 960 \quad 6888)$ and $A_2 = (1 \quad 60 \quad 48 \quad 360)$

- $$D(A_1) - \eta(W_1) I_{\eta(W_1)} = \begin{pmatrix} 2208 & 0 & 0 & 0 \\ 0 & 60 & 0 & 0 \\ 0 & 0 & 960 & 0 \\ 0 & 0 & 0 & 6888 \end{pmatrix} - \begin{pmatrix} 4 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 \\ 0 & 0 & 4 & 0 \\ 0 & 0 & 0 & 4 \end{pmatrix}$$

$$= \begin{pmatrix} 2204 & 0 & 0 & 0 \\ 0 & 56 & 0 & 0 \\ 0 & 0 & 956 & 0 \\ 0 & 0 & 0 & 6884 \end{pmatrix}$$

$$D(A_2) - \eta(W_2) I_{\eta(W_2)} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 60 & 0 & 0 \\ 0 & 0 & 48 & 0 \\ 0 & 0 & 0 & 360 \end{pmatrix} - \begin{pmatrix} 4 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 \\ 0 & 0 & 4 & 0 \\ 0 & 0 & 0 & 4 \end{pmatrix}$$

$$= \begin{pmatrix} -3 & 0 & 0 & 0 \\ 0 & 56 & 0 & 0 \\ 0 & 0 & 44 & 0 \\ 0 & 0 & 0 & 356 \end{pmatrix}$$

The encrypted key is $2204 \;\; 56 \;\; 956 \;\; 6884, -3 \;\; 56 \;\; 44 \;\; 356$

- *Decryption*
- $B_1 = D(A_1) - \eta(W_1) I_{\eta(W_1)}$

$$= (2204 \ \ 56 \ \ 956 \ \ 6884)$$
$$B_2 = D(A_2) - \eta(W_2) I_{\eta(W_2)}$$
$$= (-3 \ \ 56 \ \ 44 \ \ 356)$$

- $C_1 = D(B_1) + \eta(B_1) I_{\eta(B_1)}$

$$= (2208 \ \ 60 \ \ 960 \ \ 6888)$$
$$C_2 = D(B_2) + \eta(B_2) I_{\eta(B_2)}$$
$$= (1 \ \ 60 \ \ 48 \ \ 360)$$

- $E(\eta(B_1)) = E(\eta(B_2)) = \frac{4}{2} = 2$

So first digit of C_1 is the 2^{nd} letter in W_1 and first digit of C_2 is 2^{nd} letter in W_2.

The order is

2208	60	960	6888
2^{nd}	3^{rd}	4^{th}	1^{st}

1	60	48	360
2^{nd}	3^{rd}	4^{th}	1^{st}

- Thus the rewritten form is $(6888 \ \ 2208 \ \ 60 \ \ 960)$ and $(360 \ \ 1 \ \ 60 \ \ 48)$.
- Adding 1, one can get $(6889 \ \ 2209 \ \ 61 \ \ 961)$ and $(361 \ \ 2 \ \ 61 \ \ 49)$, which can be written as $(83^2 47^2 5^2 + 6^2 31^2)$ and $(1^2 + 1^2 5^2 + 6^2 7^2 19^2)$. Hence one can get $(83 + 0i \ \ 47 + 0i \ \ 5 + 6i \ \ 31 + 0i)$ and $(19 + 0i \ \ 1 + i \ \ 5 + 6i \ \ 7 + 0i)$ which corresponds to the words "WORK" and "HARD".

IV. CONCLUSION

In this paper, there are two algorithms. One involving integer primes and the other uses Gaussian primes. One can maintain comparatively more secrecy in second one than that of first one. To improve much more security, one can modify the assignment by taking large primes as well as Gaussian primes.

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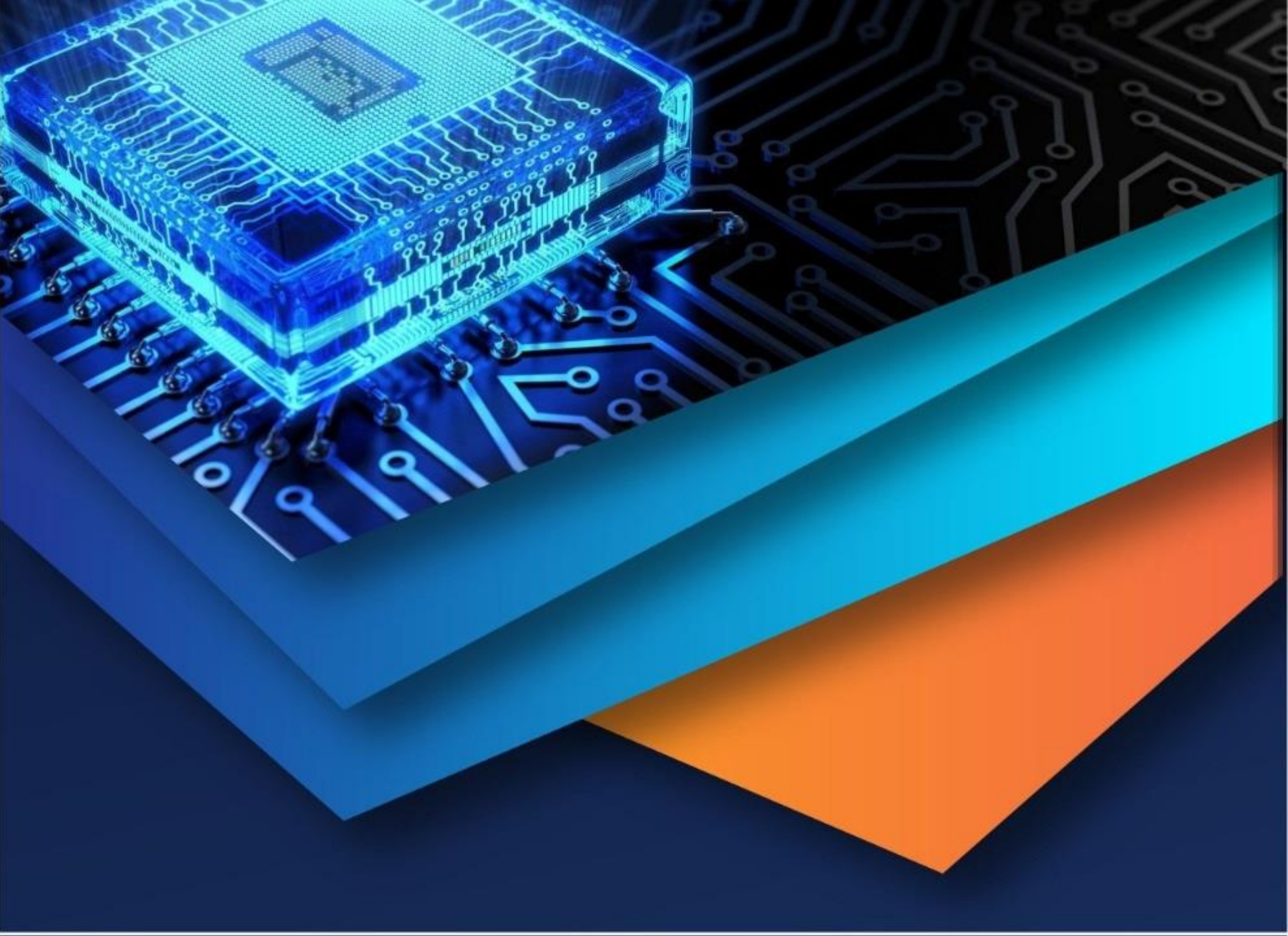

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