A NEW IMAGE ENCRYPTION ALGORITHM USING CELLULAR AUTOMATA

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Abstract: A significant part of multimedia data to be transmitted over the network consists of image data. In this paper,a cellular automata based image encryption algorithm which functions as a stream cipher has been presented. This encryption algorithm is specifically intended towards encrypting the image data. Proposed image encryption algorithm uses a hybrid cellular automata to produce a random key-stream while AES-key expansion module infuses the reasonable security in the image encryption system.

1 INTRODUCTION

There exist several image encryption techniques being developed now a days such as SCAN-based methods (Bourbakis and Alexopoulos, 1992)(Alexopoulos et al., 1995), CHAOS-based methods(Scharinger, 1998), permutation-combination based methods(Mitra et al., 2006) and cellular automata based methods(Chen et al., 2006; Chen et al., 2005; Maleki et al., 2008) etc. But, none of these image encryption systems is suitable for transmission of image content over a public communication network, as they are too slow to work as online encryption which is currently in demand. Online encryption requires a image encryption system to be fast enough to so that it can transmit the image data in real time and system should be secure enough to prevent the third party availing the image data content. The proposed image encryption algorithm has been developed to fulfill these requirements: speed and security. Proposed image encryption/decryption method is based on xor of image pixels with the corresponding pixels of the *Random Mask*. Advance Encryption Standard is well developed and tested standard in cryptography. Use of s-box in key-scheduling function of AES makes this image encryption method a non-linear function. This non linearity of the image encryption algorithm introduced by key-scheduling function provides reasonable security of the encryption scheme. Whereas, cellular automata has been used frequently in the field of cryptography as they are proved to produce pseudo random pattern very efficiently. Proposed image encryption algorithm utilizes a cellular automata and a key-expansion function of AES for the purpose of security and speed of the system. The proposed image encryption system functions in decompressed image domain *i.e* it encrypts only the decompressed image content. To encrypt a compressed image (JPEG/JBIG), compressed image must be decompressed before the encryption (Dang and Chau, 2000; Maniccam and Bourbakis, 2004; Wallace, 1999).

2 IMAGE ENCRYPTION ALGORITHM

The proposed image encryption algorithm takes as input 16-byte (128-bit) cipher key (*CK*)and encrypts a $m \times n$-pixel image, where 'm' and 'n' are variables. The image encryption algorithm belongs to the class of stream cipher and it produces blocks of key-stream in the matrix format. These blocks are called as *Random Mask* in this paper. The encryption algorithm produces series of such random masks which are later rearranged to produce a final *Random Mask* for the image. Each pixel of the image is xor-ed with the corresponding pixel of the *Random Mask* to produce an encrypted image. A sketch of the image encryption algorithm is drawn in figure 1. The 16-byte long cipher key (*CK*) is given input to the Initial Permutation function. The Initial Permutation function transforms cipher key to produce 16 intermediate keys. Each of these intermediate keys is called IK_{ip} (128-bit). The secret intermediate key IK_{ip} is taken as initial state of

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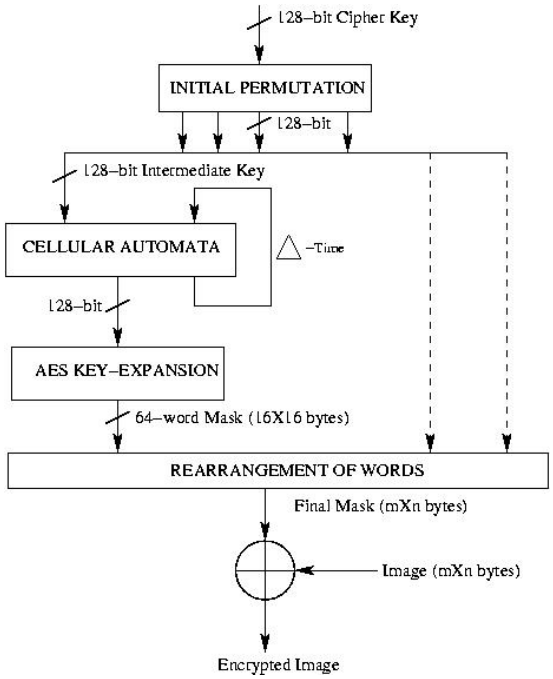


Figure 1: Outline of Encryption Algorithm.

the cellular automata. The cellular automata runs for $\triangle$ clock cycles and transforms intermediate key IK_{ip} (128-bit) into another intermediate key IK_{ip} (128-bit). IK_{ip} is given as input to the AES Key-Expansion function which expands IK_{ip} into a random mask RM_{ake} (16×16 bytes). Each pixel (1-byte) of the image is now bitwise xor-ed with the corresponding pixel (1-byte) of Random Mask, called RM_{final} after the rearrangement stage.

Algorithm 1. EncryptionAlgorithm(CK).

Input: $m \times n$ image to be encrypted.
$CK \Leftarrow CipherKey$
Output: $m \times n$ encrypted image.
$IK_{ip} \Leftarrow InitialPermutation(CK)$
for all IK_{ip} **do**
  $IK_{ca} \Leftarrow CellularAutomata(IK_{ip})$
  for all IK_{ca} **do**
    $RM_{ake} \Leftarrow KeyExpansion(IK_{ca})$
    $RM_{final} \Leftarrow Rearrangement(RM_{ake})$
  end for
end for
$E \Leftarrow I \oplus RM_{final}$

Initial Permutation linear function which iteratively applies one-byte-circular-left-shift on CK and produces 16 byte long intermediate keys, called IK_{ip}. This function outputs 16 such IK_{ip}'s, each of which are given as input to the Cellular Automata. It has been well researched that some configurations of rule 90 and rule 150 produces a pseudo random (reasonably random) pattern.(Chaudhuri et al., 1997; Serra et al., 1990; Hortensius et al., 1989) Due to this propoerty, a cellular automata based key-stream generation is adopted to speed up the process of *Random Mask* generation. The CA runs for $\triangle$ number of clock cycles producing more number of intermediate keys, called IK_{ca}. Number of clock cycles, $\triangle$, linearly increases with the size of the image to be encrypted. A pseudo code for the cellular automata used in this algorithm is given in Algorithm 2

Algorithm 2. CellularAutomata(IK_{ip}, IK_{ca}).

{Initializing Null-Boundary Conditions}
$IK_{ip}[0] \Leftarrow 0$
$IK_{ip}[17] \Leftarrow 0$
for $i = 1$ to 16 **do**
  {Randomly choose between Rule 90 and Rule 150}
  $IK_{ca}[i] \Leftarrow IK_{ip}[i-1] \oplus IK_{ip}[i+1]$
  OR
  $IK_{ca}[i] \Leftarrow IK_{ip}[i-1] \oplus IK_{ip}[i] \oplus IK_{ip}[i+1]$
end for

Since, AES key expansion function uses the Substitution Box, key-expansion is an non linear function which process the IK_{ca} word by word, where one word equal to four bytes. This function takes as input 4-word IK_{ca} and produces an array of 64 words RM_{ake} (16X16 bytes). Four words of the IK_{ca} is copied into first 4 words of the expanded key, RM_{ake}. The remainder of the RM_{ake} is filled four words at a time. Each added word w[i] depends on the immediately preceding word w[i-1], and the word 4 position back, w[i-4]. In three of four cases, a simple xor of w[i-1] and w[i-4] is used, but for a word whose position in the word array is multiple of 4, a more complex function "g" is used.

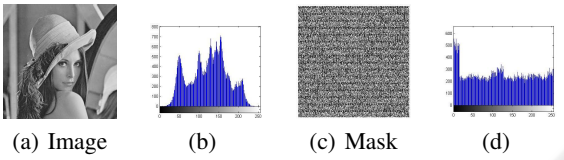
3 SECURITY OF THE IMAGE ENCRYPTION ALGORITHM

The Cellular Automata module of the image encryption algorithm uses a 128-bit linear cellular automata with a configuration of rule 90 and rule 150. It has been well studied that maximum length group cellular automata generates a very good random pattern (Bao, 2004). For a 128-bit linear cellular automata with two possible rules at each cell,the order of possible solution for this CA is 2^{128}. Hence, if rule 90 and rule 150 are applied randomly at each cell, cryptanalysis of this CA will require computation of order 2^{128}. Since, this image encryption algorithm supports variant key sizes

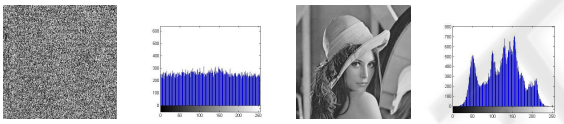
of 128, 192 and 256 bits, the cryptanalysis of higher key size CA will require computational power of order $> 2^{128}$.

3.1 Security Against Statistical Attacks

A histogram of the original image shows a biased pattern of pixel values *i.e.* some values are more likely to happen than other pixel values,because of *correlation* among the pixels of the image. This property is quite visible in the histogram shown in the Figure 2. Histogram of the *Random Mask* generated by image encryption algorithm, depicts that all pixel values are evenly distributed and the same property is forwarded into the encrypted image when original image is xored with the *Random Mask*. Histogram of the encrypted image shows an evenly distributed pattern of pixel values which makes it more robust towards any *statistical/correlation attack*.



(a) Image (b) (c) Mask (d)



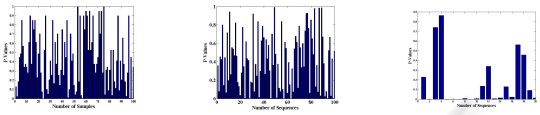
(e) After Encryption (f) (g) After Decryption (h)

Figure 2: Histogram Analysis.

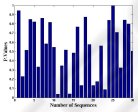
3.2 Randomness of the Computed Mask

Randomness is a probabilistic property *i.e* the properties of a random sequence can be characterized and described in terms of probability. There are 16 different test recommended by NIST (National Institute of Standards and Technology) so that statistical testing may be interpreted reasonably with out drawing any incorrect conclusions (NIST,)(NIST, 2001). For any statistical test, if the computed P-value is < 0.01, then it is concluded that the sequence is non-random. Otherwise, it is concluded that the sequence is random. Following are the used parameters for different tests.

1. **Monobit Frequency Test**
   (a) Number of Sequences/Samples = 100
   (b) Sequence Length = 10^3 bits
2. **Frequency Test within Block**
   (a) Number of Sequences/Samples = 100
   (b) Sequence Length = 10^3 bits
3. **Longest Run of Ones Test**
   (a) Number of Sequences/Samples = 20
   (b) Sequence Length = 75×10^4 bits
4. **Linear Complexity Test**
   (a) Number of Sequences/Samples = 30
   (b) Sequence Length = 75×10^4 bits
   (c) Block Length = 500



(a) Frequency Test (b) Frequency Test With in Block (c) Longest Run of Ones Test



(d) Linear Complexity Test

Figure 3: Plot of P-values for Different Tests.

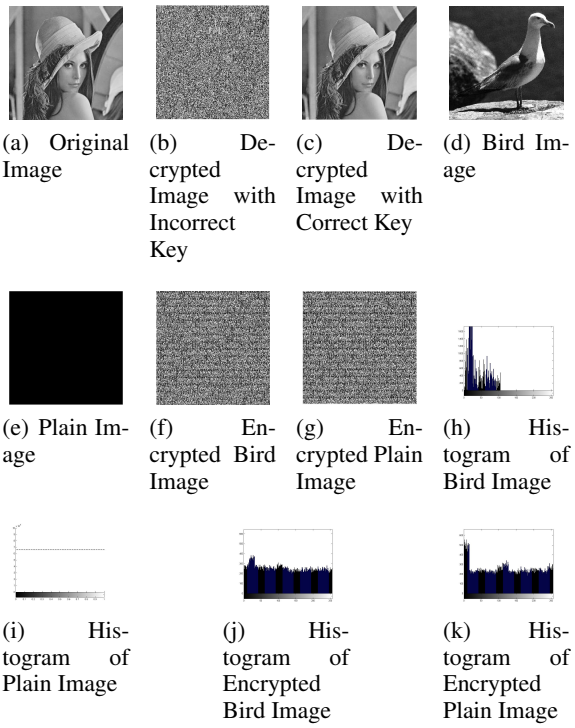
3.3 Confusion and Diffusion Properties of Encryption Algorithm

At first, decryption has been done with the correct cipher key and secondly, decryption has been done with an incorrect cipher key which differs from correct cipher key by only one bit. The decrypted image with the incorrect cipher key shows a random image even though the cipher key has been changed only by one bit.

In order to show the confusion property of the image encryption algorithm, two chosen image have been encrypted with the same cipher key and the respective histogram have been shown in Figure 4.

4 CONCLUSIONS

This image encryption scheme can lead to very efficient software as well as hardware implementation. Results from statistical tests indicate that Random Mask generated bythe image encryption algorithm is reasonably random to defy the distinguishing attack and any statistical test as well. However, more testing and cryptanalysis efforts are required to precisely assess the efficiency and security of the algorithm.



(a) Original Image (b) Decrypted Image with Incorrect Key (c) Decrypted Image with Correct Key (d) Bird Image

(e) Plain Image (f) Encrypted Bird Image (g) Encrypted Plain Image (h) Histogram of Bird Image

(i) Histogram of Plain Image (j) Histogram of Encrypted Bird Image (k) Histogram of Encrypted Plain Image

Figure 4: Different Images and their Histograms showing the Confusion Property.

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