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Selection of the Best Color Space for Image Steganography with the Least Significant Bit Method

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***Abstract*—Various kinds of security techniques have been developed to protect and maintain data confidentiality in order to avoid security problems, one of which is steganography techniques. Steganography techniques are used so that message protection or hiding secret messages does not raise suspicion for the attacker. The most commonly used steganographic embedding method is the least significant bit with image media. Current technological developments and advances make many different color spaces. However, it is not yet known the best color space for steganographic images in digital images. In this study, the performance and image quality of the eight best color spaces were compared, namely RGB, HSV, HSI, XYZ, LAB, YIQ, YUV, and YCbCr. The images used as experiments in this study are pictures of lena and baboons. The comparison results obtained with the evaluation criteria of image quality with eight measurement methods, namely NAE, NCC, MSE, PSNR, AD, MD, SC, and SSIM. Resulting that the image in the Hue Saturation Value (HSV) color space has better performance than other color spaces. This can be seen from the results of the test which got the best six values out of eight parameters for the flax image, namely HSV 1.36E-05, NCC 0.999997, MSE 0.0190582, PNSR 65.364, AD 0.0019302, and SC 1. While the baboon image got the five best values, namely MSE 0.0607897, PNSR 60.3265, MD 181, SC 1, and SSIM 0.999992.**

Keywords—Color Space, Image Processing, Least Significant Bit, Steganography

I. Introduction

In this digital era, the pattern of life is getting more accessible with information technology. Digital communication is getting easier and cheaper with the internet to send messages, data, or information. However, the internet is public, so crime in information security is increasing along with technology development. There are many ways and techniques to secure digital data, generally using data encryption [1]–[3]. Data encryption is done by changing or scrambling data so that it cannot be read, but the weakness of the encryption causes suspicion and attracts the attention of attackers. So another technique is used by hiding the data [2].

There are two data hiding techniques, namely steganography and watermarking [3]. Both have the same primary function: hiding secret messages or information, but the difference can be seen from hiding the information. Watermarking aims to protect the copyright of the cover or media cover so that the watermark is not easily damaged or deleted if an attack or manipulation is carried out on the media [4]. While the opposite steganography aims to protect the inserted message or data so that it is not easily detected directly [5].

This approach is one of the information security techniques that involves hiding secret data in other medium so that others are unaware of its existence. Steganography must be extracted precisely again because it serves to safeguard the encoded message. Incomplete extraction can change the meaning of the message, hence it must be avoided to avoid any miscommunication between the sender and the recipient. Watermarking approaches for encoding copyright typically use the frequency domain since it is more resistant to various attacks [4]. Steganography, on the other hand, employs more spatial domains because the method used in the domain is of higher quality imperceptibility and has a bigger payload capacity [6].

This study focuses on steganographic techniques that have been developed in various previous studies. Many studies have developed on the aspect of payload capacity [6]–[10], safety aspect [1], [11]–[14]. All research that has been done aims to maintain and improve the imperceptibility aspect. The payload capacity is the maximum size of messages that can be contained in a cover image. This payload capacity is usually expressed as bits per pixel (bpp). The quantity of embedding capacity has an impact on how much the pixel value of the cover image changes. The quality of the generated stego image is affected by the size of the change in pixel value of the cover image. The imperceptibility feature states that the less the pixel value changes, the better the effects may not even be detectable by human senses [10]. To measure the imperceptibility quality, one can use the peak signal to noise ratio (PSNR). This PNSR value is generated from the average squared error log value (MSE), MSE generated from calculating the original cover image and the stego image [15]. Logically, the size of the message to be embedded will significantly affect asdimperceptibility. The larger the message size, the quality of uncertainty will decrease.

Another essential thing is fidelity, namely the quality of the steganographic media does not change significantly as a result of the insertion process, recovery, which means that the inserted message can be extracted again when needed, and robustness, which means that the message content is still intact as the original, even though the steganographic media has undergone an editing process.

One of the favorite methods widely used is the Least Significant Bit (LSB) method to maintain and even improve imperceptibility in the spatial domain in the steganography technique because LSB is simple but has an excellent imperceptibility value and has a high payload capacity [8].

Previous studies have measured image quality in different color spaces using the LSB method [16]–[18]. However, the color space tested is only partially, and the measurement method is only a few parameters. So that in this study, more in-depth and detailed research was carried out. Measurement And evaluation of image quality by measurement methods Mean Square Error (MSE), Peak Signal Noise Ratio (PSNR), Normalized Absolute Error (NAE), Normalized Cross-Correlation (NCC), Maximum Difference (MD), Average Difference (AD), Structural Content (SC), and Structural Similarity (SSIM). Furthermore, the color spaces studied are Red Green Blue (RGB), Hue Saturation Intensity (HIS), Hue Saturation Value (HSV), XYZ, LAB, YIQ, YUV, and YCbCr.

So this study proves the selection of the best color space for the application of image steganography based on the tests and measurement methods carried out.

II. Related Work

Elteyeb concluded that the BMP format is better than JPG because it can accommodate more messages [19]. However, in another study, Sinha explained that the JPG file format is not effectively used in the LSB method because some data is lost due to lossy compression [20]. So that in this study, the BMP image type format was used.

Zakaria & Munir used an image with the LAB/CIELab color space model as LSB steganography media. The resulting stego image was the same as the original image and got a PSNR value of 30 dB [18]. In another study, Hiriyanna used images with the CIELab color space as LSB steganography media and obtained a PSNR value of 47 dB. The results of these studies are used as additional references in this research to be carried out.

Based on both studies [21] and [22] using several evaluation criteria, HSV was the best color space and a suitable choice for steganography. The color spaces they compare are HSV, RGB, Lab, YCbCr, and HSI.

In ataltaş & Tütüncü's research, conducted on five different color spaces, the results show that the use of HSI and XYZ/CIEXYZ color space models has better performance than RGB, YIQ, and YCbCr. His study measured the values of AD, MD, SC, NAE, NCC, MSE, PSNR, and SSIM [17], [23].

Meanwhile, in this study, other color space models were added, namely HSV, LAB, and YUV, so they became eight color spaces to find out the effect of the new color space not in the previous study.

III. The Material and Method

A. Steganography

Steganos means hidden, graphein means writing. These two Greek words are the origin of the term steganography, so that the notion of steganography is the art of writing messages hidden or embedded in specific techniques and ways. So that no one knows and realizes that there is a secret message behind the media it sends, in practice, most steganographic techniques are carried out by making slight changes to digital data that is inserted with a message so that it will not attract the attention of a third person [24].

B. Least Significant Bit

One of the embedding methods in the most widely used steganographic technique and the favorite method is the Least Significant Bit. LSB works very simply by replacing every last bit in each cover image pixel with the embedded message. The size and number of pixels in the cover image significantly affect the number of messages that can be embedded. For example, in a 24-bit image, 1 pixel consists of 3 color components to accommodate 3 bits of messages in each pixel. This means that in an image with dimensions of 512 x 512 pixels, 786,432 bits or 98,304 bytes of messages can be inserted [25].

C. Digital Image

A digital image is a numerical representation of a two-dimensional image. A digital image is represented as a matrix consisting of rows and columns where each pair of row and column indexes unites a single point in the image. The matrix value unites the brightness levels of the dots, which are referred to as pixels. Digital images are often presented as a matrix (n ¬ m) where the matrix elements are pixels [25].

D. Color Spaces

Color space, or a color model, is a way or method for organizing, creating, and visualizing colors [26]. Some of these color spaces include the following:

1) RGB

That is the color space commonly applied to CRT monitors and most computer graphics systems. This color space uses three essential components, namely red, green and blue. Each component has a value range between 0-255, thus when combined will produce 16,777,216 different color combinations.

2) HSV

The H component is the angle that states the color, S represents the purity of a color, and V is the attribute that states the amount of light from color. The formula used for transforming the RGB to HSV color space can be seen in equation (1).

$$r = \frac{R}{R+G+B}, g = \frac{G}{R+G+B}, b = \frac{B}{R+G+B}$$

$$S = \begin{cases} 0, & V = 0 \\ 1 - \frac{\min(r,g,b)}{V}, & V > 0 \end{cases}, V = \max(r,g,b)$$

$$H = \begin{cases} 0, & S = 0 \\ 60 * \left[\frac{g-b}{S*V}\right], & V = r \\ 60 * \left[2 + \frac{b-r}{S*V}\right], & V = g \\ 60 * \left[4 + \frac{r-g}{S*V}\right], & V = b \end{cases} \ldots (1)$$

3) HSI

The H component represents the actual color, such as red, violet, and yellow, the S component represents the purity level of color, and the I component is the percentage of the amount of light given into the color. The formula used for transforming the RGB to HSI color space can be seen in equation (2).

$$\theta = cos^{-1}\left\{\frac{{}^{1}/_{2}\,[(R-G)+(R-B)]}{[(R-G)^2(R-B)(G-B)]^{1/2}}\right\}$$
$$H = \begin{cases} 0, & Jika B \le G \\ 360-\theta, Jika\ B > G \end{cases}$$
$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)]$$
$$I = \frac{1}{3}(R+G+B) \dots (2)$$

4) CIEXYZ

That is the international standard color space developed by the Commission Internationale d'Eclairage (CIE). The Y component shows the luminance, while the X and Z components show the color information. The formula used for transforming the RGB to CIEXYZ color space can be seen in equation (3).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \dots (3)$$

5) CIELab

CIELab is a color space proposed by the CIE in 1931 as an international standard for color measures. CIELab has a Lightness (L) component with a range of values from 0 to 100. While the values of "a" and "b" show the green-red and blue-yellow color limits. Have a range of values from -128 to +127. The formula used to transform the CIEXYZ color space to CIELab can be seen in equation (4).

$$L^* = 116f\left(\frac{Y}{Y_n}\right) - 16$$
$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right]$$
$$b^* = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right]$$

$$f(q) = \begin{cases} q^{\frac{1}{3}}, & q > 0{,}008856 \\ 7{,}787q + {}^{16}/_{166}, & q \le 0{,}008856 \end{cases} \dots (4)$$

6) YIQ

That is the color space used by NTSC color TV in the United States. The Y component represents luminance, while components I and Q represent the hue and saturation of color with much smaller bandwidth than the luminance signal. The formula used to transform the RGB color space to YIQ can be seen in equation (5).

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix} \dots (5)$$

7) YUV

That is the color space that is usually used as part of image compression. YUV reduces the chrominance component to reduce the bandwidth of image data but has little effect on human vision. The chrominance components (U and V) are separated from the luminance components (Y) to facilitate the image segmentation process. The formula used for transforming the RGB to YUV color space can be seen in equation (6).

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \dots (6)$$

8) YCbCr

The color space resulting from the non-linear encoding of RGB values is typically used in European TV studios. Y is the luminance component while Cb and Cr are the chrominance components. Cb and Cr are the subtractive forms of blue and red, respectively. The formula used to transform the RGB color space to YCbCr can be seen in equation (7).

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.29900 & 0.58700 & 0.11400 \\ -0.16874 & -0.33126 & 0.50000 \\ 0.50000 & -0.41869 & -0.08131 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \dots (7)$$

E. Image Quality Measurement

Measurement of image quality using objective criteria is based on the allowed error limit for the processed image. For example, for the original image I(m,n) and the image that has been inserted, the message S(m,n) with the same size m x n [27]. The parameters used as objective assessment criteria in this study are:

Comparison of absolute difference value between two images is Normalized Absolute Error (NAE). The smaller the NAE value, the more similar the two images are compared. The NCC value is generated based on equation (8).

$$\text{NAE} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} I(i,j) - S(i,j)}{\sum_{i=1}^{m}\sum_{j=1}^{n} I(i,j)} \dots (8)$$

Normalized Cross-Correlation (NCC) is used to measure the comparison of the level of similarity between two images. The relationship between the two images will be more significant if the value is close to 1. The NCC value is generated based on equation (9).

$$\text{NCC} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} I(i,j) * S(i,j)}{\sum_{i=1}^{m}\sum_{j=1}^{n} I(i,j) * I(i,j)} \dots (9)$$

Meanwhile, to find out the comparison of the average value of the difference between two images, you can use the Mean Square Error (MSE). The smaller the MSE value, the less the difference between the two images being compared. The MSE value is generated based on equation (10).

$$\text{MSE} = \sum_{i=1}^{m}\sum_{j=1}^{n}\frac{[S(i,j) - I(i,j)]^2}{m * n} \dots (10)$$

The ratio between the maximum value of the measured signal and the amount of noise that affects the signal is the Peak Signal Noise Ratio (PSNR). PSNR uses decibels (dB) and is generated based on equation (11).

$$\mathrm{PSNR} = 10 * \log_{10} \frac{255}{\sqrt{MSE}} \dots (11)$$

Average Difference (AD) is the value of the difference between the two images being compared. The closer the AD value to 0, the closer the two images are. The AD value is generated based on equation (12).

$$\mathrm{AD} = \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{[I(i,j) - S(i,j)]}{m * n} \dots (12)$$

Maximum Difference (MD) shows the value of the maximum difference between the two images being compared. The MD value is generated based on equation (13).

$$\mathrm{MD} = \max(|I(i,j) - S(i,j)|) \dots (13)$$

Structural Content (SC) is a measurement method based on the similarity correlation between two images. The closer the SC value to 1, the more similar the two images are compared. The SC value is generated based on equation (14).

$$\mathrm{SC} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} I(i,j)}{\sum_{i=1}^{m} \sum_{j=1}^{n} S(i,j)} \dots (14)$$

Structural Similarity (SSIM) has a range of values between 0 and 1. A value of 1 indicates that the images being compared are identical, while a value of 0 indicates that the two images have no resemblance. The SSIM value is generated based on equation (15).

$$\mathrm{SSIM}(x,y) = \frac{(\mu_x\mu_y + C_1)(\sigma_{xy}^2 + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \dots (15)$$

F. Methodology

We used the data source from the Signal and Image Processing Institute website, USC University of Southern California [28]. Two digital images are taken for the cover image in steganography.

This research was conducted on 24 bit Lena images and Mandrill images (a.k.a. Baboon). Then the image is transformed into eight different color spaces. Next, a secret message was inserted in the form of text, namely "Kami adalah civitas akademika Universitas Siliwangi. Kami sangat bangga menjadi bagian dari kampus perjuangan Universitas Siliwangi". All the eight color space tests on the digital image were carried out and then measured the quality of the stego image objectively using eight methods.

From the tests' results, the next step is to compare and which color space has the best value. Finally, the study results are also compared with previous related studies that have been carried out.

IV. Result and Analysis

The 768 KB "lena.bmp" image and 786 KB "baboon.bmp" image before and after the insertion process are presented in Table 1. Based on the human senses, there is no significant change in the image after the message is inserted, and the size of the image is not experiencing changes.

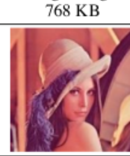
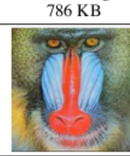
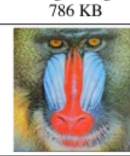
Furthermore, the test of measuring stego image quality was carried out objectively using eight methods of measuring image quality, namely Normalized Absolute Error (NAE), Normalized Cross-Correlation (NCC), Mean Square Error (MSE), Peak Signal Noise Ratio (PSNR), Average Difference (AD), Maximum Difference (MD), Structural Content (SC), and Structural Similarity (SSIM).

Table 2 shows the results of image quality measurements obtained in the first image, "lena.bmp," after inserting a secret message by applying the LSB method in eight color spaces. The HSV color space got the best value based on the six measurement criteria of NAE, NCC, MSE, PSNR, AD, and SC. Meanwhile, other color spaces such as HSI, XYZ, and LAB only get two criteria, and the RGB color space, YUV, and YCbCr, only one criterion.

The second experiment for applying the LSB method on the "babon.bmp" image can be seen in table 3. Again, the results show that the HSV color space gets the best results, namely getting the best five out of eight assessment criteria.

Combining the scores from the two images, namely, the color space that is the most superior is HSV based on eight measurement criteria. Furthermore, HSI and LAB get four measurement criteria. The XYZ color space is three criteria, and RGB, YUV, and YCbCr are only two criteria. Meanwhile, YIC from the two images of Lena and Baboon did not get the best score based on the eight assessment criteria, so the score was abysmal.

TABLE I. Lena and Baboon Image Message Insertion

Color Space	Cover Image 768 KB	Stego Image 768 KB	Cover Image 786 KB	Stego Image 786 KB
RGB				

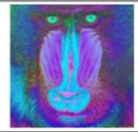
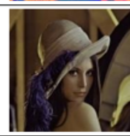
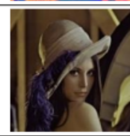
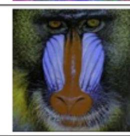
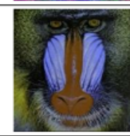
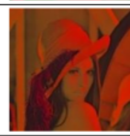
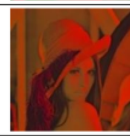
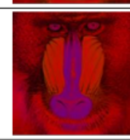
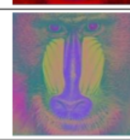
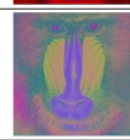
HSV				
HSI				
XYZ				
LAB				
YIQ				
YUV				
YCbCr				

TABLE II. IMAGE QUALITY MEASUREMENT LENA.BMP

Color Space	Measurement Method							
	NAE	**NCC**	**MSE**	**PNSR**	**AD**	**MD**	**SC**	**SSIM**
RGB	1.69E-05	0.999996	0.0506096	61.1225	0.0020154	181	**1**	0.99999
HSV	**1.36E-05**	**0.999997**	**0.0190582**	**65.364**	**0.0019302**	102	**1**	0.999994
HSI	1.89E-05	**0.999997**	0.0408071	62.0574	0.0019455	166	1.00001	**0.999995**
XYZ	3.58E-05	**0.999997**	0.104256	57.9838	0.0022634	215	**1**	0.99994
Lab	1.37E-05	0.999996	0.0240351	64.3563	0.0021464	**98**	**1**	0.999969
YIQ	4.81E-05	0.999987	0.0739899	59.4731	0.0022151	191	1.00001	0.999983
YUV	0.000474	**0.999997**	0.108953	57.7924	0.0020752	255	0.999543	0.999978
YCbCr	1.75E-05	0.999995	0.0522779	60.9816	0.0022062	140	**1**	0.999977

TABLE III. IMAGE QUALITY MEASUREMENT BABOON.BMP

Color Space	Measurement Method							
	NAE	**NCC**	**MSE**	**PNSR**	**AD**	**MD**	**SC**	**SSIM**
RGB	1.90E-05	0.999996	0.155047	56.2602	0.002449	250	**1**	0.999958
HSV	2.20E-05	0.999996	**0.0607897**	**60.3265**	0.0021579	**181**	**1**	**0.999992**
HSI	2.67E-05	0.999997	0.0721232	59.584	**0.002121**	182	**1**	0.99999

XYZ	3.61E-05	0.999996	0.160479	56.1106	0.0024338	255	**1**	0.999917
Lab	**1.48E-05**	0.999996	0.0797145	59.1494	0.0022176	201	**1**	0.999965
YIQ	1.54E-04	0.999991	0.157942	56.1798	0.0024045	255	0.999931	0.999967
YUV	0.0002389	**0.999998**	0.157219	56.1998	0.0022558	255	0.999792	0.999967
YCbCr	1.75E-05	0.999996	0.0867996	58.7796	0.002182	218	**1**	0.999964

The next step is to compare the histogram values of the original cover image with the stego image in all color spaces, but in this paper, it is shown only in the RGB color space as an example.

If seen by the naked eye in Figure 1 or Figure 2, the two do not have the slightest difference. Figure 1 is a histogram of Lena's cover image, while Figure 2 is a histogram of her stego image. Likewise, Figures 3 and 4 show there is no difference in the results of the baboon image trial. We do not show the histograms for other images in different color spaces because they have the same result.

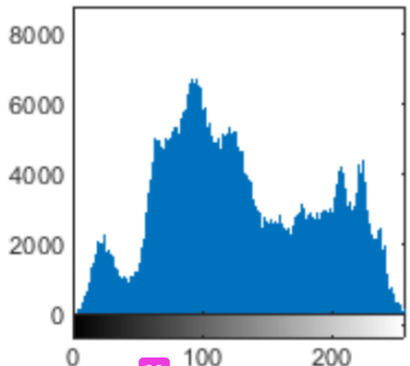


Fig. 1. Lena Cover Image Histogram

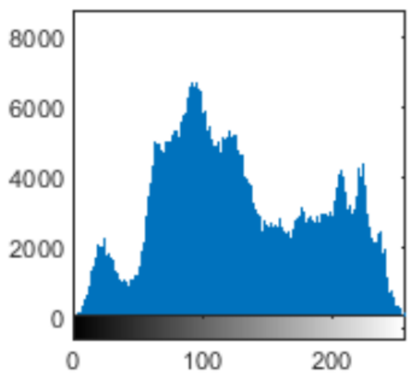


Fig. 2. Lena Stego Image Histogram

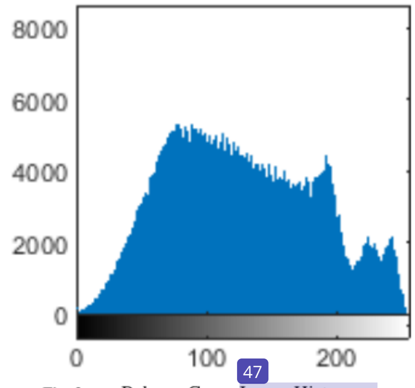


Fig. 3. Baboon Cover Image Histogram

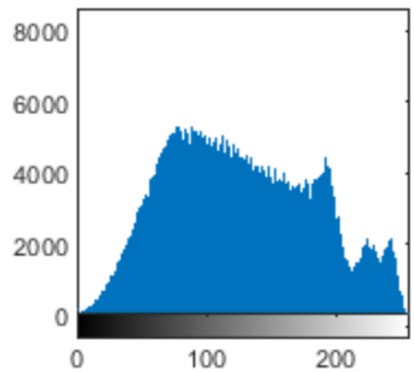


Fig. 4. Baboon Stego Image Histogram

V. CONCLUSIONS

This study proved that the use of digital images with eight color spaces, including RGB, HSV, HSI, XYZ, LAB, YIQ, YUV, and YCbCr, was tested successfully applied as a steganography medium using the LSB method. Furthermore, after the results are compared, our evaluation criteria that reflect the image quality show that Hue Saturation Value (HSV) is a color space that has better performance and results than other color space models for use in image steganography techniques with the least significant bit method.

The results of this study get new facts that replace the results of previous studies, which only compared the five color spaces outside the RGB, HIS, XYZ, YCbCr, and YIQ color spaces to conclude the best HIS.

In the future, we plan to perform additional compression tests on different image types. We also desire to explore further the security and strength of stego image resilience against various cryptographic attacks.

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