QAM-DWT-SVD Based Watermarking Scheme for Medical Images

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ABSTRACT

This paper presents a new semi-blind image watermarking system for medical applications. The new scheme utilizes Singular Value Decomposition (SVD) and Discrete Wavelet Transform (DWT) to embed a textual data into original medical images. In particular, text characters are encoded by a Quadrature Amplitude Modulation (QAM-16). In order to increase the security of the system and protect then the watermark from several attacks, the embedded data is submitted to Arnold Transform before inserting it into the host medical image. To evaluate the performances of the scheme, several medical images have been used in the experiments. Simulation results show that the proposed watermarking system ensures good imperceptibility and high robustness against several attacks.

I. INTRODUCTION

With the widespread emergence of internet and computer applications, medical images can be shared between specialists and hospitals to determine suitable diagnostic procedures [6] and improve the understanding of a certain disease [9]. However, sharing medical images can lead data to be submitted to an act of tampering by unauthorized persons. As a result, a lot of worry has grown about the protection of authenticity, integrity and confidentiality of the content of medical images.

To avoid this kind of issues, image watermarking can be used as an effective and promising solution [4]. Image watermarking consists of hiding data into the original image without causing serious degradation of the perceptual quality [5]. In the inverse process, the watermark should be recovered from the watermarked image that can be disturbed by several attacks.

Image watermarking algorithms can be classified based on different views [19]. In terms of human perception, image watermarking can be grouped into visible and hidden methods. Visible watermarks such as logos are inserted into the corners of images for content or copyright protection. On the other side, hidden watermarks are imperceptible and are inserted on the unknown places in the host image. The similarity between the watermarked data and the original one should be high, in such a way that a simple user cannot make a difference. Image watermarking can also be categorized into fragile and robust, blind and non-blind.

In addition to above groupings, the digital image watermarking can be also classified into two groups according to the domain used for data embedding. The algorithms of the first group use the spatial domain for data embedding. In this case, the watermark is inserted by directly modifying the pixel values of the host image [12, 13]. In general, spatial methods are easy to implement but they are very fragile against attacks especially lossy compression. Moreover, the inserted data can be easily detected by computer programs since the watermark is embedded in the spatial domain of the image. The algorithms of the second group take advantage of transformation domains in which the watermark is embedded by modulating the coefficients in a transform domain such as
Singular Value Decomposition (SVD) is an important technique of linear algebra that can be used to solve several mathematical problems. SVD is widely applied in many varieties of image processing applications such as image steganography, image watermarking, image compression and noise reduction [14].

From the perspective of linear algebra, a digital image can be viewed as a matrix composed of a number of non-negative scalars. The SVD of an image $A$ with size $M \times N$ is represented mathematically as

$$A = U S V^T$$  \hspace{1cm} (1)

where $U$ and $V$ are the orthogonal matrices such that $U U^T = I_M$, $V V^T = I_N$, the columns of $U$ are the orthonormal eigenvectors of $AA^T$, the columns of $V$ are the orthonormal vectors of $A^T A$, and $S$ is a diagonal matrix containing the square roots of the eigenvalues from $U$ or $V$ in descending order.

If $r$ is the rank of the matrix $A$, then the elements of the diagonal matrix $S$ satisfy the following relation:

$$\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_r \geq \lambda_{r+1} = \lambda_{r+1} = \ldots = \lambda_n = 0$$  \hspace{1cm} (2)

SVD has several interesting properties in image processing applications such as stability, proportionality, rotation and translation, etc. SVD can represent efficiently the intrinsic algebraic properties of an image. Indeed, the brightness of the image is specified by the singular values and corresponding pair of singular vectors reflect the geometry of the image.

The main goal of using SVD-based watermarking techniques is to insert the data into the singular values by applying the SVD into whole or small blocks of the host image. Unlike the other watermarking methods, SVD can be utilized for non-square matrices because of its nonsymmetrical decomposition property. In general, SVD-based watermarking algorithms are robust against geometric attacks such as rotation, translation, noise addition and scaling. However, SVD still remains limited in comparison with transform domain methods. In order to increase the robustness, SVD can be combined with transform techniques such as DCT and DWT.

### B. Discrete Wavelet Transform (DWT)

Discrete Wavelet Transform (DWT) is a multi-resolution mathematical tool that decomposes hierarchically an image and can be efficiently implemented using different digital filters. An image can be passed through high and low pass filters in order to be decomposed into several sub-bands with different resolutions. By applying DWT, the image is decomposed into four components namely LL, LH, HL and HH, corresponding to approximate, vertical, horizontal, and diagonal features respectively as illustrated in Fig. 1. The sub-band denoted by LL is approximately half of the original image. While LH and HL sub-bands contain the changes of edges or images along horizontal and vertical directions. Fig. 2 presents an example on 1-level DWT decomposition of Lena image that shows the four sub-bands LL, LH, HL and HH.
C. Arnold Transform (AT)

Arnold transform is a 2D chaotic map that is used to randomize a watermark matrix before embedding it into a cover image. Although there are many ways for scrambling, in this paper, we will discuss only the Arnold transform [17] to increase the robustness and improve the security of the proposed watermarking scheme.

Arnold transform is an iterative process of moving the pixel position. Suppose that the original image is a \( N \times N \) array and the coordinate of the pixel is \((x, y)\in \{0, 1, \ldots, N–1\}\). The generalized two dimension (2D) Arnold transform is defined as:

\[
\begin{pmatrix}
x_n \\
y_n
\end{pmatrix} = \begin{pmatrix}
1 & k \\
l & kl + 1
\end{pmatrix} \begin{pmatrix}
x_{n-1} \\
y_{n-1}
\end{pmatrix} \mod N
\]  

(3)

where \(x_n\) and \(y_n\) are the transformed coordinates corresponding to \(x_{n-1}\) and \(y_{n-1}\) after \(n\) iterations respectively, \(k\) and \(l\) are positive integers, and \(N\) represents the width or height of the square image processed.

Arnold transform is a periodic process, so the original position of \((x; y)\) coordinates gets back after \(T\) iterations. The factor \(T\) is called the transform period and depends on parameters \(k; l\) and \(n\). These parameters will be used as secret keys in this paper. To recover the original image, periodicity is required. If the scrambling has performed \(n\) iterations; then the original image can be obtained by performing \(T–n\) iterations. Fig. 3 illustrates an example of Arnold Transform into an image with different iterations.

D. Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation is a form of modulation that is a combination of phase modulation and amplitude modulation. A diversity of communication protocols implement quadrature amplitude modulation (QAM) such as digital video broadcast (DVB) and 802.11b wireless Ethernet (Wi-Fi).

For QAM-16, 4 bits are collected and mapped to one symbol from an alphabet with \(2^4 = 16\) possibilities called constellations [11].

The symbols of QAM-16 alphabet are the complex numbers in the set \(\{\pm3\pm3j, \pm3\pm j, \pm1\pm3j, \pm1\pm j\}\). The QAM-16 constellation is shown in Fig. 4. In this work, we use QAM-16 for encoding text characters to insert them into the host image.

Let \(z\) be a symbol in constellation QAM-16; \(z = a + jb\) where \(a, b \in \{-3, -1, 1, 3\}\) \(z\) can be also represented in the polar form as: 

\[z = \rho e^{j\theta}\] 

where \(\rho = \sqrt{a^2 + b^2}\) and \(\theta = \text{angle}(z)\). Table I shows the correspondence between the binary codes and the complex symbols.

| Binary code | Real part | Imaginary part | \(\rho\)   | \(\theta\) (degree) |
|-------------|-----------|----------------|-----------|-------------------|
| 0000        | -3        | -3             | 4.2426    | -135              |
| 0001        | -3        | -1             | 3.1623    | -161.5651         |
| 0010        | -3        | 3              | 4.2426    | 135               |
| 0011        | -3        | 1              | 3.1623    | 161.5651          |
| 0100        | -1        | -3             | 3.1623    | -108.4349         |
| 0101        | -1        | -1             | 1.4142    | -135              |
| 0110        | -1        | 3              | 3.1623    | 108.4349          |
| 0111        | -1        | 1              | 1.4142    | 135               |
| 1000        | 3         | -3             | 4.2426    | -45               |
| 1001        | 3         | -1             | 3.1623    | -18.4349          |
| 1010        | 3         | 3              | 4.2426    | 45                |
| 1011        | 3         | 1              | 3.1623    | 18.4349           |
| 1100        | 1         | -3             | 3.1623    | -71.5651          |
| 1101        | 1         | -1             | 1.4142    | -45               |
| 1110        | 1         | 3              | 3.1623    | 71.5651           |
| 1111        | 1         | 1              | 1.4142    | 45                |

Because the \(\theta\) values will be used in a watermark matrix, the periodicity of sine and cosine functions can be used to change the negative values of \(\theta\) by a positive values \((\theta + 360^\circ)\) as shown in Table II.
TABLE II. CORRESPONDENCE BETWEEN BINARY CODES AND COMPLEX SYMBOLS WITH $\emptyset > 0$

| Binary code | Real part | Imaginary part | $\rho$ | $\emptyset$ (degree) |
|-------------|-----------|----------------|-------|---------------------|
| 0000        | 0         | 0              | 4.2426| 225                 |
| 0001        | 0         | -1             | 3.1623| 198.4349            |
| 0010        | 0         | 3              | 3.1623| 135                 |
| 0011        | 0         | -1             | 1     | 161.5651            |
| 0100        | -1        | -3             | 3.1623| 251.5651            |
| 0101        | -1        | -1             | 1.4142| 225                 |
| 0110        | -1        | 3              | 3.1623| 108.4349            |
| 0111        | -1        | 1              | 1.4142| 135                 |
| 1000        | 3         | -3             | 4.2426| 315                 |
| 1001        | 3         | -1             | 3.1623| 341.5651            |
| 1010        | 3         | 3              | 3.1623| 18.4349             |
| 1011        | 3         | 1              | 1.4142| 315                 |
| 1100        | 1         | -3             | 3.1623| 288.4349            |
| 1101        | 1         | -1             | 1.4142| 225                 |
| 1110        | 1         | 3              | 3.1623| 71.5651             |
| 1111        | 1         | 1              | 1.4142| 45                  |

Table III is obtained by sorting Table II according to the $\rho$ column. It is remarkable that the angles $\{315, 225, 135, 45\}$ corresponding to magnitudes 4.2426 or 1.4142 as the rest of the angles correspond to the magnitude 3.1623. In this work, we use this correspondence to extract QAM-16 symbols. The symbols extraction decision is made in two stages: firstly the extraction of $\emptyset$ and secondly the extraction of $\rho$ based on correspondence between $\rho$ and $\emptyset$. For example, if the extraction of $\emptyset$ belongs to $\{341.5651; 251.5651; 288.4349; 198.4349; 161.5651; 108.4349; 71.5651; 18.4349\}$ $\rho$ is automatically equal to 3.1623 and if the extraction of $\emptyset$ belongs to $\{315; 225; 135; 45\}$. Finally, we make a decision of $\rho$ on 4.2426 and 1.4142.

III. THE PROPOSED APPROACH

The overall system of our proposed approach is illustrated in Fig. 5. First, we convert the electronic patient record (ERP) text into a watermark matrix using the QAM-16, then Arnold Transform is applied to the watermark matrix and the watermark is scrambled. The parameters of Arnold Transform are used as a key to increase the security of the watermark. The scrambled watermark matrix is embedded then into the host image. To recover the secret data, the scrambled watermark matrix is extracted from the watermarked image using the extraction procedure. Finally, the inverse Arnold Transform and QAM-16 procedure are successively applied to retrieve the original ERP data. The proposed algorithm consists of six main steps:

1. Conversion ERP text into a watermark matrix.
2. Scrambling the watermark matrix by Arnold Transform.
3. Embedding process.
4. Extraction process.
5. Inverse Arnold Transform.
6. Conversion watermark matrix to the original ERP.

A. Watermark Matrix

In this work, the watermark that is embedded in the original medical image is a matrix that is generated from the EPR. The characters of the EPR text are grouped into a matrix of size $2^m \times 2^m$. For example, an EPR of 1024 characters is represented in a matrix of size $2^8 \times 2^8$. Then, the ASCII code for each character $i$ is converted to 8-bit binary code.

The QAM-16 is applied to the first 4 bits and the last 4 bits to obtain two pairs $(\rho_1, \emptyset_1)$ and $(\rho_2, \emptyset_2)$ which are grouped into a matrix of size $2 \times 2$ as shown in Fig. 6.

To ensure that the watermark matrix elements are between 0 and
we use \( \rho \) rather than the magnitude \( \rho \) and \( \phi \) rather than the angle \( \phi \). After this process, the resulted watermark matrix is obtained by replacing each character by a 2 × 2 matrix that is composed by \( \rho \) and \( \phi \) which gives a watermark matrix of size \( 2^{m+1} \times 2^{m+1} \).

![Diagram of character conversion process](image)

**Example**

Let \( tex = "Farabi2 hospital" \), the size of \( tex \) is 16 characters that can be grouped into \( 2^2 \times 2^2 \) matrix by replacing each character to its ASCII code. The resulted matrix is:

\[
\begin{bmatrix}
70 & 98 & 104 & 105 \\
97 & 105 & 111 & 116 \\
114 & 58 & 115 & 97 \\
97 & 32 & 112 & 108 \\
\end{bmatrix}
\]

By applying the process as shown in Fig. 6, we convert each ASCII code to a \( 2 \times 2 \) matrix:

\[
\begin{bmatrix}
\rho_1 & \phi_1 \\
10 & 360 \\
\phi_2 & \rho_2 \\
360 & 10 \\
\end{bmatrix}
\]

Then, the resulted watermark \( 2^3 \times 2^3 \) matrix is:

\[
\begin{bmatrix}
0.3162 & 0.6988 & 0.3162 & 0.3012 & 0.3162 & 0.3012 & 0.3162 & 0.3012 \\
0.3012 & 0.3162 & 0.3750 & 0.4243 & 0.8750 & 0.4243 & 0.9488 & 0.3162 \\
0.3162 & 0.3012 & 0.3162 & 0.3012 & 0.3162 & 0.3012 & 0.1414 & 0.3750 \\
0.5512 & 0.3162 & 0.9488 & 0.3162 & 0.1250 & 0.1414 & 0.6988 & 0.3162 \\
0.1414 & 0.3750 & 0.3162 & 0.4488 & 0.1414 & 0.3750 & 0.3162 & 0.3012 \\
0.3750 & 0.4243 & 0.3750 & 0.4243 & 0.4488 & 0.3162 & 0.5512 & 0.3162 \\
0.3162 & 0.3012 & 0.4243 & 0.3750 & 0.1414 & 0.3750 & 0.3162 & 0.3012 \\
0.5512 & 0.3162 & 0.6250 & 0.4243 & 0.6250 & 0.4243 & 0.8012 & 0.3162 \\
\end{bmatrix}
\]

**B. Watermark Embedding Process**

The proposed watermark embedding process is described as follows:

**Input**: Original Image \( I \) of size \( 2^J \times 2^J \), Watermark matrix of size \( 2^K \times 2^K \)

**Output**: Watermarked Image \( \hat{I} \)

1. DWT level \( l = J - K \)
2. Apply \( l \)-level DWT on the original image \( I \) to produce four sub-bands \( LL, LH, HL \), and \( HH \),
3. Perform SVD operation for low-pass sub-band \( LL \),
\[
LL = U_L S_L V_L^T
\]
4. Modify \( S_L \), the singular values of the sub-band \( LL \), by adding a watermark matrix, with the scaling factor \( \alpha \),
\[
S_2 = S_L + \alpha W
\]
5. Compute SVD of \( S_L \),
\[
S_2 = U_2 S_2 V_2^T
\]
6. Using \( S_2 \) to compute a modified low-pass sub-band \( LL' \),
\[
LL' = U_L S_2 V_L^T
\]
7. Compute the watermarked image \( \hat{I} \) by applying the inverse DWT on \( LL', LH, HL \), and \( HH \).

**C. Watermark Extraction Process**

In general, the extraction process can be completed by reversing the steps of the embedding process. In watermark extraction, an eventually distorted watermark \( W \) can be extracted from the eventually distorted watermarked image \( \hat{I} \) by effectively reversing the above watermark embedding steps. The process of watermark extraction can be described as follows:

**Input**: Watermarked Image \( \hat{I} \)

**Output**: Watermark matrix

1. Apply \( l \)-levels DWT on the watermarked image to produce four sub-bands \( LL, LH, HL \), and \( HH \),
2. Compute SVD of low-pass sub-band \( LL \),
\[
LL = U_L S_L V_L^T
\]
3. Compute \( S_L \) using left and right singular vectors \( U_L \) and \( V_L \) in step 5 in watermark-embedding algorithm
\[
\hat{S} = U_2 S_2 V_2^T
\]
4. Extract the watermark matrix \( \hat{W} \),
\[
\hat{W} = \frac{\hat{S} - S_L}{\alpha}
\]

**IV. Experimental Results**

To evaluate the performances of our proposed scheme, we have applied the embedding algorithm to a database of 100 grey scale medical images of four modalities: X-ray, Ultrasound, MRI and CT. All test images are \( 512 \times 512 \) pixels. An example of these medical images is illustrated in Fig. 7.
A. Quality Measures

Peak Signal to-Noise Ratio (PSNR) is one of the most commonly used measures of imperceptibility between an original image $I$ of size $M \times N$ and a watermarked image $I_w$, which is computed by:

$$PSNR = 10\log\left(\frac{\max(I(i,j)^2)}{MSE}\right)$$

(4)

$$MSE = \frac{\sum_{i=0}^{N-1} \sum_{j=0}^{M-1} (I(i,j) - I_w(i,j))^2}{NM}$$

(5)

Structural Similarity Measure (SSIM) is another perceptual metric that quantifies the watermarked medical images quality. Image quality evaluation based on SSIM is based on the fact that the HVS is highly adapted to extract structural information from the viewing field. SSIM metric is ideal for testing of similarities in medical images because it focuses on local rather than global image similarity.

$$SSIM(A, B) = \frac{(2\mu_A\mu_B + c_1)(2\sigma_{AB} + c_2)}{\mu_A^2 + \mu_B^2 + \sigma_{AB}^2 + c_1(c_1 = kL)^2}$$

(6)

where $\mu_A$ and $\mu_B$ are respectively the averages of $A$ and $B$. $\sigma_A^2$ and $\sigma_B^2$ are respectively the variances of $A$ and $B$. $c_1(c_1 = kL)^2$ and $c_2 = (kL)^2$ are constants.

Fig. 7. (a) CT, (b) MRI, (c) X-Ray and (d) Ultrasound.

Fig. 8. Curve of Peak Signal to Noise Ratio (PSNR) in dB for different medical images modalities (a) CT, (b) X-Ray, (c) MRI and (d) Ultrasound.
\(c_1(c_2 = k_2L)^2\) are two variables to stabilize the division with a weak denominator. \(L\) is also the dynamic range of the pixel-values. \(k_1\) and \(k_2\) have default values as 0.01 and 0.03, respectively [18].

In order to compare the similarities between the original ERP text and the extracted ERP text, we define the character error rate in percentage (CER) as follows:

\[
CER = \frac{NEC}{TC}
\]

(7)

where:
- NEC: number of erroneous characters
- TC: total number of characters in a ERP text

**B. Imperceptibility Medical Images**

In this subsection, we investigate the imperceptibility of the watermark. The PSNR is used to measure the similarity between the original image and the watermarked image. When the PSNR value is higher than 30 dB, it will be difficult to find the difference between the original image and the watermarked image on human’s eyes [10].

Fig. 8 (a)-(d) show the PSNR for different medical images modalities by embedding an ERP text of 2048 characters (2kb). The PSNR values reached for these 100 images are between 57.5306 dB and 66.0223 dB, which demonstrate that the proposed method achieves good imperceptibility.

**C. Similarity for Different Embedded Data**

Fig. 9 represents the PSNR values for different number of embedded characters from 128 (\(2^7\)) characters to 16384 (\(2^{14}\)) characters on four medical images CT, X-Ray, MRI and Ultrasound. We can notice that the value of PSNR decreases when number of embedded characters increases. On the other side, the PSNR values are greater than 45 dB, which mean that embedded data is undetectable according to the human visual perception.

**D. Comparison to Existing Scheme**

To prove the effectiveness of the proposed scheme, our method is compared with another semi-blind scheme [1]. The watermarked image is attacked by applying salt & pepper noise and Gaussian noise in order to investigate the robustness.

In Table IV, we analyzed the variation of character error rate (CER) against varying density of Salt and Pepper for some images. For the proposed technique, we observe that the value of Character Error Rate (CER) is equal to zero for all density of Salt and Pepper noise, which means that the extraction of ERP text is done without any error and indicating the highly robust nature of our technique against Salt and Pepper noise. However, in the case of the Sleit’s method, we observe that the Character Error Rate (CER) value increases as the density of noise increases, and that causes a deterioration of detection performance.

| Salt & Peppers noise density | Methods | 10^{-6} | 10^{-5} | 10^{-4} |
|-----------------------------|---------|---------|---------|---------|
| Proposed                    | 0       | 0       | 0       |
| Sleit                       | 0       | 0       | 4.6294  |
| Proposed                    | 0       | 0       | 0       |
| Sleit                       | 0       | 0       | 3.2109  |
| Proposed                    | 0       | 0       | 0       |
| Sleit                       | 2.8645  | 4.7582  | 32.5897 |
| Proposed                    | 0       | 0       | 0       |
| Sleit                       | 25.8245 | 32.5638 | 63.8453 |

**TABLE IV. VARIATION OF CER ON DIFFERENT VALUES OF SALTS & PEPPERS ATTACK**
TABLE V. VARIATION OF CER ON DIFFERENT VALUES OF GAUSSIAN ATTACK

| \( \sigma_w \) | Methods | \( 10^{-6} \) | \( 10^{-5} \) | \( 10^{-4} \) |
|-----------|---------|-------------|-------------|-------------|
| \( 0 \)   | Proposed | 0           | 0           | 0           |
| \( 6.1275 \) | Sleit     | 0           | 0           | 5.7835      |
| \( 0 \)   | Proposed | 0           | 0           | 0           |
| \( 6.1275 \) | Sleit     | 0           | 0           | 6.2578      |
| \( 0 \)   | Proposed | 0           | 0           | 0           |
| \( 56.7582 \) | Sleit     | 56.7582     | 61.2878     | 73.9245     |

Table V shows the robustness against Gaussian noise with different variances. We can observe that the CER value of Sleit’s method is significantly higher than our method. It is also clearly that the CER value of the proposed method is equal to zero for all Gaussian noise values, which ensures an extraction without any error.

To further validate the robustness of the proposed scheme we compare it with the scheme presented in [1]. The considered disturbances are compression, low-pass filter (median filter) and speckle noise. From Table VI, it is obvious that our proposed system outperforms the algorithm introduced in [1] for all disturbances and for all test images. We notice also the compression deteriorates highly the watermark by using Sleit scheme [1] especially for MRI and CT images. Table VI indicates also that the robustness of our method against compression is much higher than the method in [1] and it guarantees the quality of the images with that mentioned behavior.

V. CONCLUSION

This paper presents a new watermarking scheme for medical images. The proposed scheme is based on a combination of DWT and SVD to embed the watermark in a transparent manner and extracted it with high fidelity. QAM-16 was also used to encode text characters and insert them into the host image. Overall, the proposed scheme demonstrates a good trade-off between of imperceptibility, robustness, and capacity as compared to state of the art methods. Our experimental results show the effectiveness of combination of wavelet algorithm with SVD technique as compared to non-hybrid SVD or DWT methods in terms of PSNR and SSIM.

In the future work, we will aim to overcome the limitation of the proposed semi-blind watermarking by extending it to the blind context. In particular, we will focus in reversible image watermarking by evaluating the performance with much more image types including not only medical image but also texture and biometric images.

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TABLE VI. CER RESULTS UNDER VARIOUS ATTACKS

| Attack          | Proposed scheme | Sleit scheme |
|-----------------|-----------------|--------------|
|                 | X-ray Ultrasound | MRI CT       | X-ray Ultrasound | MRI CT |
| Compression (Q=80%) | 1.1254 1.6113 9.6845 8.2651 | 7.4852 11.2635 35.9475 31.4763 |
| 3 × 3 Median filter | 0.4882 1.2695 1.1718 3.5644 | 5.8492 9.2383 8.3962 12.3549 |
| Speckle noise   | 0.3662 0.4882 0.5859 0.7324 | 4.7482 15.2375 22.6534 8.4742 |
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