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Research Article

Keywords: Video copyright, Blockchain, Zero-watermarking, Privacy, Key-frames extraction

Posted Date: July 14th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-288335/v2>

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Version of Record: A version of this preprint was published at EURASIP Journal on Wireless Communications and Networking on March 21st, 2022. See the published version at <https://doi.org/10.1186/s13638-022-02090-x>.

A novel zero-watermarking scheme based on NSCT-SVD and blockchain for video copyright

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Abstract

With the advent of information era, issues about video copyright continue to emerge. In the grey industrial chain of piracy, the film industry is a major disaster area so far. The current protection schemes for video copyright are inefficient and costly so that video industry still has to face the infringement. Research on a simple and efficient protection technology of video copyright is urgent. To address the inefficiency and irregularity of the current protection schemes for video copyright, this paper proposes a simple and efficient protection scheme for video copyright based on video zero-watermarking and blockchain. The results show that key-frames extraction and key-frames zero-watermarking based on NSCT-SVD in the proposed video zero-watermarking algorithm perform well and achieve low-cost protection for video copyright in practical environment. In addition, video zero-watermarking algorithm of proposed scheme works well with blockchain. Proposed scheme improves some extent on database centralization and evidential difficulties of traditional video zero-watermarking schemes, and it is more reliable, simpler and more effective than traditional video zero-watermarking schemes without blockchain.

Keywords: Video copyright, Blockchain, Zero-watermarking, Privacy, Key-frames extraction

1 Introduction

Since the turn of the millennium, the demand for video has risen quickly with the development of video products. However, some illegal video application damage the owners' copyrights. Against this background, a reliable protection scheme for video copyright has become extremely necessary and urgent in 21st century.

The development of technology for copyright protection is closely related to the demand for video copyright protection. With video springing up as the main way of information dissemination all over the world, there is a greater need for protection scheme of video copyright. In particular, TikTok, YouTube and Hollywood, the three organizations that represent the three most dominant approaches in video industry today (such as short-form video, self-published video and digital cinema). They all have a quite

1 strong need for reliable protection scheme of video copyright. Hollywood loses 64.6 billion dollars for
2 pirated videos every year. TikTok and YouTube are even more so.

3 Unfortunately, in the world wide, the priority of current research is still more on traditional image
4 copyright authentication and less on video copyright authentication. The video copyright authentication
5 still needs to be developed. Considering of the application prospects of reliable protection scheme for
6 video copyright, the urgency of copyright owner's demands and the importance of economy development,
7 researches on video copyright protection are supported by a number of government agencies around the
8 world.

9 With the continuous research on information hiding, digital watermarking technology of information
10 hiding technology has been applied in the field of copyright protection. However, the traditional video
11 blind watermarking schemes lack public credibility and are easy to be detected and attacked, and cannot
12 be well qualified to verify video copyright. Traditional video zero-watermarking schemes are recognized
13 by the trusted third-party. But in situation of the cyberspace security, the centralized management still
14 has some problems. Therefore, zero-watermarking scheme with decentralized management is one of the
15 best solutions. In conclusion, the main problems of existing watermarking schemes on video copyright
16 protection are as follows.

- 17 • Poor robustness: There is a high probability that the watermark will be corrupted after multi-
18 transform in the current network architecture or compression. So that it becomes ineffective for
19 video copyright.
- 20 • Weak imperceptibility: The addition of watermark to some videos has a visually perceptible
21 impact on the original quality of the video, making it less commercially viable.
- 22 • Single function: Most current schemes have single function on copyright authentication.
23 However, in an actual scenario of copyright protection, there will be some functions such as
24 traceability of rights. The deficiency of existing schemes makes the actual process of rights
25 maintenance quite complicated.

26 In proposed scheme, to solve these pressing issues about poor robustness and weak stealthy of existing
27 protection schemes, we design a video key-frames extraction algorithm based on distance threshold
28 clustering and a colour zero-watermarking algorithm based on combination of Non-Subsampled
29 Contourlet Transform (NSCT) with Singular Value Decomposition (SVD). We innovatively combine
30 video zero-watermarking algorithm with blockchain to address problem on data management and
31 traceability of rights in current scheme for video copyright [1].

32 The remaining part of the paper is organized as follows. The related works are in *Related works* which
33 introduces the development of digital watermarking applied to copyright protection, lists the examples
34 about the new technology applied to copyright protection, and describes the watermarking algorithms
35 proposed by related scholars detailed. The proposed scheme is elaborated in *Scheme*. Firstly, the overall
36 architecture of system for video copyright protection is introduced, and how to combine zero-
37 watermarking with blockchain to realize copyright protection function is explained. Secondly, we
38 introduce the extraction algorithm of the key-frames from video. Thirdly, we introduce a zero-
39 watermarking algorithm on key-frames based on NSCT and SVD. *Results* shows the experimental results

of proposed scheme, and the reliability is verified. The security and privacy of proposed scheme are discussed in *Discussion*. Lastly, works of this paper are concluded in *Conclusions*.

2 Related works

Among the techniques which are used to protect digital intellectual property, digital watermarking of information hiding technology is the most popular. The creation of digital watermarking could be dated back to 1954, when Emil Hembrooke of Muzak applied for a patent. The patent is applying a narrowband trap filter with a central frequency of 1 kHz to insert a verification code. This system was used by Muzak until 1984. Research on digital watermarking began in the early 1990s. The concept of digital watermarking was first introduced at the International Conference on Image Processing in 1994 [2], and then the First International Symposium on Information Hiding was held in the UK in 1996 [3]. At the Third International Symposium on Information Hiding in 1999, digital watermarking dominated the conference, with 18 of the 33 papers were devoted to the study of digital watermarking. Currently, digital watermarking has evolved towards copyright protection for any types of digital files.

In the previous works, scholars from all over the world have made a great progress in the study of digital watermarking on images. KOBAYASHI Atsushi, HASEGAWA Akria and et al. propose that digital watermarking algorithms can be embedded in edge devices as a complement to other permission management and they investigate the application of digital watermarking to both still images and moving images [4]. He Fang studies on wavelet-based high-frequency and low-frequency methods for inserting watermark and tests their anti-compressibility for watermark extraction. The experiments show that the insertion of watermark in the high frequency domain keeps the original quality better, and the insertion of watermark in the low frequency domain makes the robustness better [5]. Zai-rong WANG, Babak SHIRI's innovatively use fractional logistic mapping for generating chaotic sequences, then encrypt and insert the watermark into the original image. Because the fractional order of the encrypted image is within $(0,1]$, the key space is increased [6]. Their research provides a robust and safe watermarking method in the protection of the copyright of hardware, image and other electronic documents [6]. Yuan-Min Li and Deyun Wei propose a watermarking algorithm with double encryption based on cosine transform and fractional Fourier transform in the invariant wavelet domain. Their work innovatively utilises image magnification technique to pre-process the host image to enhance embedding capacity of the watermarking algorithm. They use the redistribution-invariant wavelet transform and the discrete cosine transform to obtain the hybrid domain, and they also propose a multi-parameter particle swarm optimisation algorithm, which is used to obtain the optimal embedding factor matrix [7].

Zero-watermarking [8] has become a focus of research in recent years since it was proposed by Wen Quan, as it did not make any modification to the original digital file. Zhiqiu Xia and Xingyuan Wang et al. propose multiple zero-watermarking scheme based on local quaternion polar harmonic Fourier moments (QPHFMs) for colour medical images, and the construction of multiple zero-watermarking effectively improves reliability and resists complex out-of-step attacks, such as clipping [9]. Hongfei Xue and Wanda Chi propose a more robust zero-watermarking algorithm based on NSST, DCT and Hessenberg decomposition. They innovatively generate a zero-watermark by performing XOR between the QR code and the characteristic matrix of a colour image [10]. In recent years, the combination of deep learning and watermarking algorithm has been also a key research area. Ali Amiri and Satter Mirzakuchaki propose an intelligent watermarking model based on NSCT-SVD. They innovatively use

1 PSO-GA-AI algorithm, and the obtained PSO and PSO-GA algorithms with larger SF have higher
2 stability, then low frequency coefficient is fed back to the SVD through NSCT and SWT so that the
3 values of model visual transparency and PSNR will increase [11].

4 Video is a very important part of the digital media. Currently, there are three types of schemes about
5 video watermarking. The first way is the watermarking scheme based on original video, which is about
6 embedding the information of watermark into the original video. It should be noted that the first way is
7 our choice in proposed scheme. The second way is based on the video encoding process. The
8 compression standards of mainstream video include the MPEG series of ISO/IEC and the H.264 series
9 of ITU-T [12,13], and the key technology to achieve a high compression ratio is predictive coding and
10 transform coding. The disadvantage of the second way is the presence of cumulative errors which can
11 have an adverse effect on video quality [14]. The third way is based on the compressed domain. Because
12 the video is currently transmitted and stored after compression, the third way is based on the compressed
13 domain. The advantage of this way is that the embedded watermarking doesn't need to be re-encoded
14 and decoded, so it can reduce computational complexity through this way. The disadvantage is that the
15 low redundancy of the compressed data limits the amount of data that can be watermarked, and the
16 embedding strength is limited by the encoding of the video data. Y Sun and J Wang remedy the
17 shortcomings of the existing watermarking algorithms on H.264/SVC framework. Their research uses
18 DCT (the discrete cosine transforms) and an invisible watermarking framework with scalable
19 watermarking algorithms to accommodate the multi-resolution of H.264 / SVC, and they design control
20 mechanisms of key to select sub-blocks adaptively from macroblocks [15]. Their proposed method
21 achieves no less than 41 dB peak signal-to-noise ratio (PSNR) and a normalised correlation (NC) of >0.85
22 [15]. Yicheng Qiu and Feng Xue et al. propose a novel method of video watermarking for HEVC (High
23 Efficiency Video Coding) that the blocks for watermarking embedding are selected based on the temporal
24 and spatial characteristics of the compressed video, which minimizes the synchronization error and can
25 well prevent collusion attacks [16]. Besides, the public key is extracted from features of compressed
26 domain to select the blocks for embedding, and the watermark is embedded on the blocks which reduces
27 the computational overhead [16].

28 Except using digital watermarking for copyright protection, PetaPixel develops Blockkai which uses
29 the Bitcoin blockchain to protect copyright, and Baidu's "Totem" uses blockchain technology to solve
30 the pain point of image copyright [17]. Tencent Cloud uses blockchain technology to launch the "Zhixin
31 Chain" to solve the problem of original content protection. Byte Dance's Tuchong has a deep partnership
32 with Ant Blockchain of Ant Financial. Currently, Tuchong becomes the leading platform based on
33 blockchain for the identification and ownership of photographers and the copyright of original works can
34 be checked on the chain [18].

35 **3 Methods**

36 **3.1 Structure**

37 In this part, we will introduce how does the video zero-watermarking algorithm work with blockchain
38 for protecting copyright. First of all, the main processes of registration about video copyright are as
39 follows.

- 40 • Step 1. User A uploads a video and a colour image which is used for identity authentication, then

- 1 authenticates identity through the terminal.
- 2 • Step 2. Pre-process the video data and extract the key-frames by distance threshold clustering.
 - 3 • Step 3. Construct zero-watermarks on extracted key-frames.
 - 4 • Step 4. Collect zero-watermarks, information of key-frames and Key K_2 , then package these
 - 5 data.
 - 6 • Step 5. After the terminal constructs and signs the data package into a proposal, the proposal is
 - 7 sent to the access node in the blockchain network, and the access node broadcasts the proposal
 - 8 after verification.
 - 9 • Step 6. After receiving the block, the node verifies the proposal and composes the proposal into
 - 10 a block to be verified, and sends it to each node for processing. When more than two thirds of
 - 11 the nodes reach a consensus, the nodes start to generate blocks, then send them to blockchain
 - 12 network.
 - 13 • Step 7. Blockchain network checks information of block (for example, block height) and each
 - 14 node will store a complete block and table data.
 - 15 • Step 8. The terminal returns the Key K_1 to User A by terminal.

16 Secondly, this proposed scheme uses the blockchain to realize the transactions of copyright. Compared
17 with complicated operations in other solutions, the blockchain is more practical, and it is born to solve
18 the trading problems. The main processes of copyright transaction are as follows.

- 19 • Step 1. User B sends a proposal, which is constructed and signed by terminal and sent to the
- 20 access node.
- 21 • Step 2. The consensus node receives the proposal and takes out a number of proposals from pool
- 22 in the order of the queue. After that, it will assemble them as consensus blocks and then send
- 23 them to each node for processing.
- 24 • Step 3. After the node receives the block, the proposal is taken out of the block and executed in
- 25 order, and the results of execution are packaged in the transaction receipt and returned.
- 26 • Step 4. The nodes exchange their execution results. When more than 2/3 of the nodes have the
- 27 same execution result, the node will start to generate blocks and permanently storage the
- 28 transaction and execution results to hard disk.

29 Thirdly, the main processes for certification on video copyright are as follows.

- 30 • Step 1. In order to authenticate the video, User A needs to provide Key K_1 and the block hash to
- 31 match other information on the blockchain to get the information of key-frames, zero-watermarks
- 32 and Key K_2 on the chain.
- 33 • Step 2. Use the watermark extraction algorithm to return a colour watermark which can
- 34 authenticate the identity and complete the authentication.
- 35 • Step 3. User B can simply check ledger on the blockchain network when he completes the
- 36 transaction to prove his copyright of the video.

37 The above processes are described in Fig. 1.

Fig. 1 Architecture of the protection system

3.2 Key-frames extraction

The main processes of key-frames extraction algorithm are as follows.

- Step 1. Input video samples and process the video library.
- Step 2. Convert unstructured dynamic video into a static sequence of video frames.
- Step 3. Process the samples initially and extract the feature vectors.
- Step 4. Calculate the inter-frame similarity and distance threshold according to the extracted feature vectors to complete the clustering.
- Step 5. Judge key-frames according to the clustering results.
- Step 6. Output the extracted key-frames.

3.2.1 Feature extraction

The selection of feature is very important to the expression of key-frames and the completion of effective clustering. Colour and texture features are common image features. At present, most of the key-frames extraction algorithms are based on clustering use colour histogram, but the feature of colour histogram cannot describe colour space distribution between adjacent pixels. As a local feature of an image, texture feature does not depend on colour and brightness. It not only reflects the grey level statistics of the image, but also reflects the spatial distribution information and structure information of the image. Its grey level invariability and rotation invariant can cleverly avoid experimental errors caused by significant changes in light. Therefore, in this paper, the completed LBP (CLBP) [19] descriptor of the improved local binary patterns (LBP) [19] is chosen to handle the texture features. CLBP texture descriptor [20] is an extended

texture descriptor based on LBP descriptor [21], which can effectively describe the missing information of LBP type in order to obtain better performance of texture classification.

Usually, given a central pixel and other P neighbourhood values, the local difference vector is expressed as $[d_0 \dots d_{p-1}]$, $d_p = g_p - g_c$, s_p and m_p are the sign (positive or negative) and magnitude values of d_p using the local difference sign-separation-magnitude transform (LDSMT), respectively.

The above content is shown as follows:

$$d_p = s_p \cdot m_p \text{ and } \begin{cases} s_p = \text{sign}(d_p) \\ m_p = |d_p| \end{cases} \quad (1)$$

and

$$s_p = \begin{cases} 1, d_p \geq 0 \\ -1, d_p < 0 \end{cases} \quad (2)$$

The above formulas cannot be used directly as a descriptor because it is sensitive to light, rotation, noise, etc. The difference between the neighbouring pixels and the central pixel is divided into a sign component and a gradient component and is obtained by multiplying the two together, denoted as CLBP_S and CLBP_M.

For example, Fig. 2a is a sampling block which is size of 3×3 , which can be divided into Fig. 3a $\times$ Fig. 3b, and its difference can be represented by Fig. 2b. Fig. 3a is sign components, and Fig. 3b is gradient components. Actually, CLBP_S is the traditional LBP, and the two coding methods are the same. -1 in Fig. 3a is equal to 0 in the traditional LBP. What's more, the CLBP_S is more capable to describe texture than the CLBP_M. Formula of CLBP_S is shown as follows:

$$CLBP_S_{P,R} = \sum_{p=0}^{P-1} s(s_p) 2^p \quad (3)$$

and

$$s(x) = \begin{cases} 1, x \geq 0 \\ 0, x < 0 \end{cases} \quad (4)$$

9	12	34
10	25	28
99	64	56
(a) 3px*3px image		

-16	13	9
15		3
-74	39	31
(b) Local Difference Images		

Fig. 2 Description of CLBP algorithm I

-1	-1	1
-1		1
1	1	1
(a) CLBP_S		

16	13	9
15		3
74	39	31
(b) CLBP_M		

Fig. 3 Description of CLBP algorithm II

Fig. 4 CLBP algorithm

It can be seen from Fig. 3b, CLBP_M is a continuous value. In order to harmonise the encoding with CLBP_S, it needs to be converted to binary encoding as well. Inspired by CLBP_S, this paper follows the following encoding for them, c is an adaptive threshold, and the value of c is taken as the mean value of m_p in the whole image. m_p is the absolute value accumulation of gradient differences between neighbourhood pixels and centre pixels (or the average of them, the final results of comparison are equal). Formula of CLBP_M is shown as follows:

$$CLBP_M_{p,R} = \sum_{p=0}^{p-1} t(m_p, c) 2^p \quad (5)$$

and

$$t(x, c) = \begin{cases} 1, & x \geq c \\ 0, & x < c \end{cases} \quad (6)$$

The central pixel represents the local grey level and also contains the local grey level discriminant information. In order to effectively combine it with CLBP_M and CLBP_S, we carry out the following encoding:

$$CLBP_C_{p,R} = t(g_c, c_l) \quad (7)$$

and

$$t(x, c) = \begin{cases} 1, & x \geq c \\ 0, & x < c \end{cases} \quad (8)$$

In Eq. 7, g_c represents the centre pixel grey value, c_l represents the average grey value of the whole image. Binary encoding is performed by comparing the centre pixel and the average pixel value of the entire image.

The process of CLBP algorithm is shown in Fig. 4. After the above calculation, the three descriptors CLBP_S, CLBP_M, CLBP_C are all generated, which can be fused in the form of series, parallel or series-parallel histogram, and can achieve more effective rotation invariant classification ability than the traditional LBP.

3.2.2 Inter-frame similarity

Distance measurement is used to measure the distance between individuals in space. The farther the distance is, the greater the difference between individuals is, and the lower the similarity is. Chi-square distance is the most common measure to measure the difference between two individuals, and its calculation is simple. Therefore, in this paper we use chi-square distance to represent the similarity between frames. The smaller the chi-square distance is, the higher the similarity between frames is. The chi-square distance between any two frames is defined as follows:

$$dist(F_a, F_b) = \sum_{i=1}^n \frac{(F_a[i] - F_b[i])^2}{F_a[i] + F_b[i]} \quad (9)$$

In Eq. 9, $F_a[i]$ and $F_b[i]$ represent the values of image a and image b on the binary bit i. Respectively, n is the total number of video frame histogram bins, and $dist(F_a, F_b)$ represents the inter-frame similarity.

3.2.3 Distance threshold

The distance threshold directly affects the number of clusters, thereby affecting the extraction efficiency of key-frames. If the threshold is too small, it is easy to extract too many key-frames, resulting in information redundancy. If the threshold is too large, the extracted key-frames cannot represent the main content of the lens. According to the idea of data density sampling [23], the distance threshold is defined as follows:

$$d = \frac{2c}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N dist(F_i, F_j) \quad (10)$$

In Eq. 10, N is the total number of video frames, and $\frac{N(N-1)}{2}$ is the number of chi-square distances between two N frames. c is a constant. A large number of experiments show that the value of 0.25 in this algorithm is better. d is the distance threshold of clustering algorithm obtained by density sampling. By this method, different thresholds can be selected for different videos, which reflects the adaptability of the threshold. The threshold selected by this method will be small but not too small, and appropriate small threshold can obtain more initial clustering, which is conducive to cluster centre merging and secondary clustering.

3.2.4 Description of clustering

All the steps of algorithm description are shown as follows.

Fig. 5 Process of clustering algorithm

- 1 • Step 1. Sample the data set to determine the distance threshold d.
- 2 • Step 2. Initial clustering of data sets is based on threshold and similarity, and then determine the
- 3 initial number of clusters k and cluster centre set C.
- 4 • Step 3. Use K-means algorithm to optimize the initial clustering centre, then we get new sets of
- 5 clustering centre G.
- 6 • Step 4. Use the sequential clustering idea [24] to merge the closer classes in G, then determine
- 7 the final k and cluster centre set and cluster, and then complete the clustering centre self-
- 8 determination.

9 Process of clustering algorithm is shown in Fig. 5 (step 1 and step 2 are on the left. Step 3 and step 4
10 are on the right). After clustering, we select all the nearest frames from the clustering centre to be the
11 key-frames of the video.

12 3.3 Zero-watermarking for key-frames

13 After the digital image has been SVD [25-27], the corresponding orthogonal matrix represents the
14 geometric structure of the image while the corresponding singular matrix represents the image luminance
15 information. The real number field we define is R. Assuming the digital image matrix is A and $A \in R_{N \times N}$,
16 then Orthogonal matrix $U \in R_{N \times N}$, orthogonal matrix $V \in R_{N \times N}$ and diagonal matrix $S \in R_{N \times N}$. Therefore,
17 A can be expressed as:

$$18 \quad A = S \times U \times V^T \quad (11)$$

19 U is defined as the left orthogonal matrix and V is defined as the right orthogonal matrix. They satisfy
20 the conditions respectively, which are $U \times U^T = 1$, $V = V^{-1}$. In that S:

$$21 \quad S = \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \lambda_r \end{pmatrix} \quad (12)$$

22 A special singular value in the S matrix is usually much larger than other singular values, which can
23 represent the overall energy of A [28].

24 The Arnold Transform [29-31] can change the position of pixels and eliminate correlations between
25 pixels or content in a host image, thus improving image security. The special Arnold Transform is the
26 Simplest kind of Arnold Transform. The formula for operation of matrix is:

$$27 \quad \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \text{mod}(N) \quad (13)$$

28 The special Arnold Inverse Transform makes it easy to recover the transformed image. The formula
29 for operation of matrix is:

$$30 \quad \begin{pmatrix} x \\ y \end{pmatrix} = \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix} \text{mod}(N) \quad (14)$$

31 (x', y') denotes the position of (x, y) at the pixel point after the transformation and N denotes the size
32 of the image involved in the transformation.

33 3.3.1 Watermark generation

34 After using the key-frames extraction algorithm based on distance threshold clustering, a series of key-
35 frames are selected from the video which represent the feature information of the whole video. The zero-

watermarking algorithm is extracting the feature information of these key-frames and embedding the feature information into the watermark later. The detailed steps are as follows.

- Step 1. Output the key-frames sequence obtained by running the key-frames extraction algorithm of the previous part, denoted as Frame I. The size of the frame is $M \times N \times 3$.
- Step 2. Perform RGB decomposition on the key-frames and get three grey-scale images, denoted as I_R, I_G, I_B . Then make I_R, I_G, I_B , the three grey-scale images into $A \times B$ non-overlapping chunks (Operations on the separated three frames are the same and we will only introduce one in the following). Suppose the values of M and N are both 512, and the values of A and B are both 128. The chunking method is as follows.

$$B_{i,j} = \frac{I_k^{M \times N}}{A \times B}, k \in \{R, G, B\}, i, j \in \{1, 2, 3, 4\} \quad (15)$$

- Step 3. Do Arnold Transform on each sub-block, and the disordering key is Key K_1 . Assume that the chunked sub-blocks are transformed according to Eq. 13. The Arnold Transform will disrupt correlation between pixels of the grey-scale.
- Step 4. Do NSCT for each sub-block $B_{i,j}$ after scrambling. The NSCT yields low-frequency information $cA_{i,j}$ for each sub-block containing point singularities and curve singularities. Following the assumptions in step 2, The size of $cA_{i,j}$ is 32×32 .
- Step 5. Subdivide the low frequency component $cA_{i,j}$ again and subdivide $cA_{i,j}$ into sub-blocks of 4×4 size. The chunking method is as follows.

$$cB_{m,n} = \frac{cA_{i,j}}{8 \times 8}, m, n \in \{1, \dots, 8\}, i, j \in \{1, \dots, 4\} \quad (16)$$

- Step 6. Do SVD [32] on each sub-block according to Eqs. 8 and 9. The method is as follows.

$$[U_{i,j}, S_{i,j}, V_{i,j}] = SVD(cA_{i,j}) \quad (17)$$

Owing to the highest bit of each singular value matrix of each sub-block does not change under a certain range of attacks, the maximum singular value of each singular value matrix is chosen to construct the characteristic matrix X. After SVD, characteristic matrixes $\{X_R, X_G, X_B\}$ can be get. Characteristic matrix X is as follow.

$$X = \begin{bmatrix} f_{1,1} & \cdots & f_{1,32} \\ \vdots & \ddots & \vdots \\ f_{32,1} & \cdots & f_{32,32} \end{bmatrix} \quad (18)$$

- Step 7. Process a meaningful watermark image, and its size is $m \times n \times 3$. After the RGB decomposition, get the three grey-scale images, denoted as I_R', I_G', I_B' , then do Arnold Transform on I_R', I_G', I_B' and it's the distorting key is Key K_2 . Assume the disordered frames are W_R', W_G', W_B' .
- Step 8. Do NSCT on W_R', W_G', W_B' , then get high frequency parts which are denoted as H_R', H_G', H_B' and the low frequency parts which are denoted as L_R', L_G', L_B' . Run XOR $\{H_R', H_G', H_B'\}$ and $\{L_R', L_G', L_B'\}$ with each of the three channels of the characteristic matrixes $\{X_R, X_G, X_B\}$ obtained in step 6. The method is as follows.

$$Z_{KH} = XOR(X_k, H_K'), K \in \{R, G, B\} \quad (19)$$

$$Z_{KL} = XOR(X_k, L_K'), K \in \{R, G, B\} \quad (20)$$

Fig. 6 Process of watermark generation

- Step 9. Do the inverse NSCT on Z_{KH} and Z_{KL} , then composite RGB channels to produce a colour zero-watermark. The method is as follows.

$$Z_{KH} + Z_{KL} = Z_K, K \in \{R, G, B\} \quad (21)$$

$$Z_{R,G,B} = Z_R + Z_G + Z_B \quad (22)$$

All the above steps are shown in Fig. 6.

3.3.2 Watermark extraction

The extraction method is organized as follows.

- Step 1. Based on the information of the Frame I, obtain the sequence of key-frames.
- Step 2. Follow step 2 in *Watermark generation* for RGB decomposition and chunking.
- Step 3. Use Key K_1 to do Arnold Transform like step 3 in above watermark generation for each of the chunked sub-blocks.
- Step 4. Follow step 4, step 5 and step 6 in above *Watermark generation*. After those Steps, characteristic matrixes which are denoted as X_R , X_G , X_B are generated.
- Step 5. Process colour zero-watermark, and it is size of $m \times n \times 3$. After the RGB decomposition, the separated frames which are denoted as I_R , I_G , I_B . Do NSCT on I_R , I_G , I_B , then get the high frequency parts which denoted as H_R , H_G , H_B and the low frequency parts which are L_R , L_G , L_B . Run XOR $\{H_R, H_G, H_B\}$ and $\{L_R, L_G, L_B\}$ with each of the three channels of the characteristic matrixes $\{I_R, I_G, I_B\}$. The method is as follows:

1 to verify the process of extracting the features on key-frames in the video and obtained zero-watermark
2 which was recorded on blockchain is robust and secure.

3 4.1 Experiment deployment

4 The hardware configuration of the whole experiments is shown in Table 1, and the software configuration
5 of the whole experiments is shown in Table 2.

Table 1 Hardware configuration

Environmental parameters	Config
CPU	Intel i7, 2.4GHz
GPU	GTX1080 Ti 11GB
RAM	16GB
Mainboard	Z270-AR
Hard disk	500GB SSD + 2T HDD

Table 2 Software configuration

Environmental parameters	Config
OS	Windows 10
Host Environment	Ubuntu 18.04, 64bit
Database	MySQL 8.0.18
Blockchain platforms	Fisco Bcos
Python	3.7.4
MATLAB	R2019b

Fig. 8 Images and copyright watermark

Fig. 9 Zero-watermark after extraction

Table 3 Video key-frames extraction experimental results

	Landscapes	Advertisement	Animation clips	News
Total frames	115	1254	15324	26987
CF	14	135	735	1452
Df	1	7	52	182
MF	0	2	23	85
R /%	100	98.54	96.97	94.47
P /%	93.33	95.07	93.39	88.86

In process of simulating the key-frames extraction algorithm, we choose videos with unequal length to test the actual effect of the key-frames extraction algorithm, which are *Landscapes*, *Advertisement*, *Animation clips* and *News* respectively.

In order to prove the false alarm, robustness and security of proposed zero-watermarking algorithm for key-frames based on NSCT-SVD, five images are selected to replace key-frames in experiments, which are Figs. 8(a)-8(f). Fig. 8(f) is defined as copyright watermark in experiment. All the figures are shown in Fig. 8. In Fig. 9, it is an example of generated Fig. 9(c) which is a zero-watermark constructed by Figs. 9(a) and 9(b).

4.2 Key-frames extraction

The zero-watermarking algorithm we proposed is to construct a zero-watermark based on the extracted key-frames. So, this part tests the effectiveness of video key-frames extraction algorithm which is based on K-means clustering algorithm.

This part of experiment has the following definitions: Recall ratio is denoted as R and Precision ratio is denoted as P. Correctly detection is CF. Missed detection is MF. False detection id DF. R and P are calculated as follows.

$$R = \frac{CF}{CF + MF} \quad (27)$$

$$R = \frac{CF}{CF + MF} \quad (28)$$

$$P = \frac{CF}{CF + DF} \quad (29)$$

The experimental results are shown in Table 3.

4.3 Zero-watermarking

This part reproduces the zero-watermarking algorithm based on NSCT-SVD with the images described in above, and tests the performance of the algorithm in different scenarios from false alarm, robustness, and security.

4.3.1 False alarm

The experiment content is as follows. In this experiment, we use the five images which are Figs. 8(a)-8(e) to generate the corresponding zero-watermark with the copyright watermark, and then calculate

Table 4 NC of zero-watermark between different images

Host Image	Lena	Vegetable	Bag	Ant	Animal
Lena	1.0000	0.5769	0.5125	0.4643	0.5571
Vegetable	0.5769	1.0000	0.4517	0.4943	0.3753
Bag	0.5125	0.4517	1.0000	0.5360	0.4777
Ant	0.4643	0.4943	0.5360	1.0000	0.5570
Animal	0.5571	0.3753	0.4777	0.5570	1.0000

Table 5 Comparison between DWT-SVD and NSCT-SVD

Attack Types	DWT-SVD	NSCT-SVD
Sault and pepper noise (0.03)	0.9669	0.9870
Gaussian noise (0.03)	0.9643	0.9785
Multiplicative noise (0.03)	0.9712	0.9915
Median filtering (5*5)	0.9709	0.9966
Mean filtering (5*5)	0.9752	0.9944
Wiener filtering (5*5)	0.9781	0.9987

normalized correlation (NC) between the five zero-watermarks. NC value reflects false alarm rate. The experimental results are shown in Table 4.

4.3.2 Robustness

In this part, we discuss robustness on the proposed zero-watermarking algorithm from three parts which are noise attack, filtering attack, geometric attack.

Before each attacking test on the proposed zero-watermarking algorithm, we select Fig. 8(a) to compare traditional DWT-SVD and NSCT-SVD under noise attacks and filtering attacks. We also calculate the normalized correlation between Fig. 8(a) and extracted copyright watermark after attacks. The results are shown in Table 5.

Afterwards, we test the robustness of the zero-watermarking algorithm for key-frames under noise attacks, filtering attacks and cropping attacks. The results are shown in Fig.10.

As seen from Fig. 10(a), 10(b) and 10(c), the watermarks keep visual stability well after extraction under three noise attacks. In addition, it can be seen from Fig. 10(d) that the watermark extracted after sharpening attack is still very clear. Common geometric attacks include cropping attacks, rotation attacks and row-column offsets. We have cropped one-16th and one-32th respectively in the upper left corner of the picture to test the robustness under geometric attacks. The results are shown in Figs. 10(e) and 10(f).

1 Furthermore, we use NC as a quality indicator to verify the robustness of the proposed zero-
 2 watermarking algorithm for key-frames. According to Table 6 and Table 7, the NC values obtained from
 3 watermark under the noise attacks and filtering attacks are all very high. Under noise attacks, the highest
 4 NC value is 0.9979 and the lowest is 0.9645, with the average value is 0.9812. Under filtering attacks,
 5 the highest NC value is 0.9997 and the lowest NC value is 0.9903.

6 Moreover, in order to reflect the changes of the algorithm in different intensities under noise attacks,
 7 five kinds of salt and pepper noise and multiplicative noise attacks with different intensities are carried
 8 out. The changes of NC values under different attacks intensities are shown in Fig. 11. According to Fig.
 9 11, for noise attacks, the greater the noise intensity is, the lower the NC value is.

(a) Attack of salt and pepper noise (0.03) and the extracted watermark

(b) Attack of gaussian noise (0.03) and the extracted watermark

(c) Attack of multiplicative noise (0.03) and the extracted watermark

(d) Attack of sharpening and the extracted watermark

(e) Attack of 1/16 cropping in the upper left corner and the extracted watermark

(f) Attack of 1/32 cropping in the upper left corner and the extracted watermark

Fig. 10 Results of simulation attack

Table 6 NC values obtained from watermark of the Fig. 10a-e under noise attacks

Attack Types	Parameters	Lena	Vegetable	Animal	Bag	Ant
Sault and pepper noise	0.01	0.9958	0.9957	0.9946	0.9942	0.9963
	0.03	0.9870	0.9868	0.9864	0.9875	0.9885
	0.05	0.9801	0.9811	0.9807	0.9809	0.9789
Gaussian noise	0.01	0.9914	0.9907	0.9908	0.9926	0.9932
	0.03	0.9785	0.9767	0.9777	0.9789	0.9765
	0.05	0.9667	0.9639	0.9656	0.9645	0.9658
Multiplicative noise	0.01	0.9981	0.9973	0.9978	0.9975	0.9979
	0.03	0.9915	0.9910	0.9946	0.9934	0.9961
	0.05	0.9856	0.9838	0.9919	0.9894	0.9876

Table 7 NC values obtained from watermark under filtering attacks

Attack Types	Parameters	Lena	Vegetable	Animal	Bag	Ant
Mean filtering	3*3	0.9975	0.9989	0.9977	0.9993	0.9947
	5*5	0.9944	0.9975	0.9965	0.9959	0.9976
	7*7	0.9918	0.9960	0.9953	0.9929	0.9903
Wiener filtering	3*3	0.9994	0.9998	0.9995	0.9997	0.9988
	5*5	0.9987	0.9995	0.9988	0.9987	0.9993
	7*7	0.9980	0.9993	0.9979	0.9978	0.9996
Median filtering	3*3	0.9986	0.9996	0.999	0.9978	0.9993
	5*5	0.9966	0.9991	0.9979	0.9964	0.9983
	7*7	0.9950	0.9985	0.9965	0.9959	0.9975

Fig. 11 Attack of multiplicative noise and salt and pepper noise variance

Fig. 12 zero-watermark and correctly extracted watermark

Fig. 13 watermark extracted by different parameters of Arnold Transform

4.3.3 Security

In this subsection, we sets three comparative experiments to verify the security by Arnold transform. In Fig. 12, the zero-watermark is obtained by adding Fig. 8(e) to Fig. 8(f), and watermark is correctly extracted by right secret Keys. Fig. 13(a) is extracted by wrong Keys. Fig. 13(b) is extracted by wrong scrambling rounds. Fig. 13(c) is extracted by wrong Keys and scrambling rounds.

4.4 Blockchain system

In order to verify the availability of applying blockchain to storage of zero-watermarks, this part tests the response time of the blockchain system to represent its actual efficiency, and illustrate the feasibility and rationality of the combination of the system and the blockchain.

Response time of blockchain system is one of the important indicators of system performance. The main functions of the blockchain system in proposed scheme are on-chain data entry and on-chain data traceability. Therefore, the data volume of on-chain traceability information is the key to affecting response time of the system. Fig. 14 shows the relationship between data volume of on-chain traceability information and the system response time. When the data on the chain increases from 1G to 8G, the system response time increases from 231ms to 511ms.

Fig. 14 Response time

Fig. 15 Throughput

Our scheme uses multi-threaded programming for performance testing, using each thread to simulate a user (client) interacting with the blockchain system, and conducting multiple sets of tests. Each time of test adds 3 users, and experimental data such as response time and number of requests are recorded to calculate the throughput of the system under different loads. Meanwhile, we have to monitor the server memory, CPU, network, disk read/write and other resource usage. The test is not stopping until TPS (Transaction Per Second, number of concurrent/average response time) reaches its peak. The experimental results are shown in Fig. 15. The system has not yet reached its peak when the number of simulated requests is between 3 and 27. Simultaneously, the TPS boost is stable. TPS stabilizes after the number of users exceeds 27, but decreases when it reaches 36.

4.5 Analysis

From the experimental results in Table 2, it can be seen that key-frames extraction algorithm works well for various videos. Although a small number of missed detection and false detection exist.

From the above experimental results on zero-watermarking algorithm, the proposed zero-watermarking algorithm in this paper can effectively avoid false alarm. Furthermore, our zero-watermark algorithm combined with NSCT-SVD is more robust than the traditional DCT-SVD method. Due to the combination of NSCT and SVD, the change in the low frequency coefficients of each sub-block is small under noise attacks and filtering attacks. The results show that the algorithm is robust under noise attacks and filtering attacks. Due to the block processing when constructing the feature matrix and SVD of each sub-block, so that proposed zero-watermarking algorithm can effectively resist local cropping attack. From the above experimental results, it can be seen that as long as the Keys or scrambling rounds is incorrectly, the correct watermark cannot be obtained, which fully verifies the security of Arnold Transform in proposed zero-watermarking algorithm.

According to the experimental results on blockchain system, the delay of the blockchain system is within range of technical standards of the blockchain industry. Assuming the zero- watermark is 50 kB, the data volume of the 18min short video on the chain is 71 MB. When the amount of data on the chain increases to 80GB, the system can register 18min videos about 1153, while the response time of the blockchain system is still a few seconds. In the process of testing TPS, the utilization rate of each hardware was below 100%. After comparison and inspection, it may be caused by the performance

1 limitation of Fisco Bcos. The experimental results show that the TPS of the blockchain system is about
2 216, which not only meets the performance indicators of the blockchain network, but also meets the
3 needs of the video copyright protection scheme.

4 **5 Discussion**

5 Before discussing the proposed video zero-watermarking algorithm, we compare the traditional blind
6 watermarking algorithm with zero-watermarking algorithm. The traditional blind watermarking scheme
7 is embedding the features of watermark into key-frames. The zero-watermarking algorithm is embedding
8 the features of key-frames into the watermark to generate zero-watermark. Copyright protection is
9 realized by registering zero-watermark with features of key-frames. From the perspective of visual
10 quality, the traditional blind watermarking is embedding the watermark into the key-frames, so key-
11 frames in the video will inevitably produce noise. However, zero-watermarking will not take actions on
12 key-frames so that it will not influence video quality. From the perspective of security, the traditional
13 blind watermark is easy to be detected and destroyed, even erased. But the zero-watermarking is
14 encrypted and stored in a trusted third-party, makes it hard for attackers to know where to begin.

15 In the proposed zero-watermarking algorithm, a colour video will generate many zero-watermarks
16 from extracted key-frames. The zero-watermarks generated by multiple key-frames can effectively resist
17 malicious clipping of key-frames in the actual state of secondary creation, and prevent key-frames being
18 clipped to extract effective feature matrices, so as to get the copyright watermarks. By this way, even if
19 the key-frames are clipped, watermarks which are extracted still keep a good clarity. Besides, there are
20 twice chunking in the generation of feature matrices which belongs the proposed zero-watermarking
21 algorithm. The first processing is before NSCT. When the colour video is attacked by cropping attack,
22 the coefficients after NSCT can be independent of each other. The second processing makes the
23 subsequent SVD more stable. In addition, the decomposition of RGB in this algorithm enhances security
24 of the system, because the three zero-watermarks are required to extract a colour watermark, and the
25 decomposition of RGB achieves a triple encryption logically with Arnold Transform. Above all, the
26 fundamental feature of the zero-watermarking algorithm is that copyright protection is realized without
27 any modification of the video. This zero-watermarking algorithm generates Key K_1 , which will be kept
28 by the owner of video copyright. Key K_2 can be uploaded to the blockchain network. In process of
29 copyright certification, the user provides the Key K_1 to match the key pairs (K_1, K_2) so as to extract
30 copyright watermarks from zero-watermarks on the blockchain.

31 In the video copyright protection system, the blockchain network replaces the third-party notary of the
32 traditional zero-watermarking algorithm and avoids the security issues existed in third-party notaries.
33 Furthermore, excellent security control mechanisms exist in the blockchain. The system applied in the
34 field of video copyright protection have high demand for data security, so access control of data on the
35 alliance chain is required, whose strategy is mainly divided into the following two aspects.

- 36 • Access control of communication data on the chain is accomplished through node certificates
37 and SSL.
- 38 • In the access control of node storage data, the blockchain uses disk encryption, which is
39 performed within the institution. In the institution's intranet, each institution independently
40 encrypts the node's rigid disk data. When the rigid disk of the machine is away from the institution

and the node is allowed to start up on a network outside the institution's intranet. The rigid disk data will not be decrypted and the node will not be able to start up and thus steal the data on the federated chain.

In addition, the data on the chain (the colour zero-watermark) has been scrambled. Even if being accessed, no valuable information can be obtained. Copyright rights transactions will only be done on the blockchain network without any further manipulation on the video. This way is more efficient than traditional methods. For example, all permission transactions and permission ownership information will be recorded on the blockchain network and be protected from malicious tampering. Thus, the malicious user uses and reproduces a video illegally, a legally valid proof will be found through fast traceability in the video copyright protection system.

6 Conclusions

Aiming at the problems of the traditional watermarking scheme for video copyright, such as poor robustness, weak imperceptibility and single function, we propose a zero-watermarking protection scheme for video copyright based on blockchain and NSCT + SVD.

In our scheme, firstly, the proposed key-frames extraction algorithm performs high accuracy in filtering key-frames. Secondly, we choose the NSCT which is combined with the Nonsubsampled Pyramid (NSP) and the Nonsubsampled Directional Filter Bank (NSDFB) in zero-watermarking algorithm. This method can decompose the images in multi-scale and multi-direction, making up for the deficiency that wavelet transform only has three directions of vertical, horizontal and diagonal transformation of the image. It has good translation invariance, making up for the shortcomings of contourlet transform sampling. Thirdly, zero-watermarking algorithm based on SVD after chunking can achieve the stability in the process of zero-watermarking, and zero-watermarking method makes video quality not be affected. Fourthly, the difficulties in security and efficiency of video copyright protection are overcome by combining blockchain and the video zero-watermarking algorithm.

Further works are as follows.

- Investigate a low-cost copyright protection method based on blockchain and digital watermarking technology for derivative work problem (The malicious person modifies the video and then claims to be original).
- Investigate a combination system of IPFS and blockchain to increase the storage capacity on the blockchain.
- Study cross-chain key technologies so as to realize protection of cross-domain video copyright.

Abbreviations

NSCT: Non-Subsampled Contourlet Transform; PSNR: peak signal-to-noise ratio; SVD: Singular Value Decomposition; DCT: the discrete cosine transforms; QPHFMs: quaternion polar harmonic Fourier moments; HEVC: High Efficiency Video Coding; NC: normalized correlation; LDSMT :local difference sign-separation-magnitude transform; LBP: local binary patterns; CLBP: completed LBP; TPS: Transaction Per Second, number of concurrent/average response time; NSP: Nonsubsampled Pyramid; NSDFB: Nonsubsampled Directional Filter Bank.

Acknowledgments

1 We sincerely thank the Reviewers and the Editor for their valuable suggestions.

2 **Authors' contributions**

3 Xiangqi Wu and Peng Ma conceived and designed this research together. Xiangqi Wu designed the framework of this program.
4 Peng Ma designed the core algorithm. Zihan Jin and Yuxuan Wu investigated and wrote the paper. Wei Ou Provide financial sup
5 port and guidance. All authors reviewed and approved final manuscript.

6 **Funding**

7 Not applicable.

8 **Availability of data and materials**

9 Not applicable

10 **Declarations**

11 **Competing interests**

12 The authors declare that they have no competing interests.

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Figure title and legend

Fig. 1 Architecture of the protection system. It shows the whole process about USER A's registration and verification. And it includes the USER B' get-permission and verification;

Fig. 2 Description of CLBP algorithm I. The matrix of sampling block and its local difference are (a) and (b);

Fig. 3 Description of CLBP algorithm II. Sign components, and gradient components are (a) and (b);

Fig. 4 CLBP algorithm. Original image is classed by CLBP;

Fig. 5 Process of clustering algorithm. It demonstrates from the input of the video to the determination of the final k, clustering centre set and clustering;

Fig. 6 Process of watermark generation. The watermark information is encrypted and embedded in the key frame;

Fig. 7 Process of watermark extraction. The watermark information is decrypted and extracted from the key frame;

Fig. 8 Images and copyright watermark. All images used in our scheme;

Fig. 9 Zero-watermark after extraction. (a) and (b) generate a zero-watermark image (c);

Fig. 10 Results of simulation attack. The result of various attacks on the image;

Fig. 11 Attack of multiplicative noise and salt and pepper noise variance. Five kinds of multiplicative noise attacks (a) and salt and pepper noise attacks (b) with different intensities are carried out. Blue, orange, red, yellow and purple represent lena, vegetable, animal, bag, and ant images;

Fig. 12 Zero-watermark and correctly extracted watermark. The result of successfully extracting the watermark;

Fig. 13 watermark extracted by different parameters of Arnold Transform. Watermark results extracted by different keys incorrectly;

Fig. 14 Response time. Changes in response time as the volume of data increases;

Fig. 15 Throughput. Changes in TPS as the number of users increases;