Digital Resource Rights Confirmation and Infringement Tracking Based on Smart Contracts

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Abstract: The protection of digital resource copyrights has drawn extensive public concern in the past decade. Traditional methods, however, fail to satisfy the requirements due to their poor timeliness, frequent infringement, and cumbersome in rights confirmation, etc. In this paper, we investigate and design a novel approach for cross-platform digital resource rights confirmation and infringement tracking based on smart contracts. We utilize smart contracts to realize rights transactions and protection. As another contribution, we propose to establish fine-grained digital resource rights, which are divided into ownership and usufruct. For tracking infringement acts, we invoke smart contracts to extract the rights transfer chain for resources. Furthermore, we reveal the source of resource leakage by embedding digital watermarks when distributing the resources. By combining resource rights transfer chain and digital watermarking, we can effectively achieve digital resource rights confirmation and infringement tracking. Extensive experiments show the effectiveness of our proposed method.

Keywords: Blockchain; Smart contract; Copyright protection; Infringement tracking; Digital watermarking

1 Introduction

Copyright protection [4, 5] for digital resources is one of the fundamental problems in multimedia security. Digital resource protection aims to effectively control the usage of resources on the Internet, by providing real-time copyright owner determination and prevent unauthorized use. Current digital resource protection systems, however, face severe problems, such as difficult copyright confirmation, poor timeliness, frequent infringement, etc. Besides, there is still a lack of research efforts toward cross-platform infringement source identification and tracking. Conventional resource copyright transactions are generally carried out by signing a copyright transaction consensus to achieve confirmation. We would like to point out that this method suffers from several severe drawbacks like low transparency and difficult rights protection. This not only results in inefficiencies but also bears the inherent risk of information being tampered and leaked. Moreover, traditional digital resource platforms also have the following problems. First, when infringement occurs, it is extremely difficult to track and identify the source of the leakage and hard to conduct real accountability directly on these infringements. Second, as to the digital resource rights, there still exists a lack of fine-grained rights classification. For instance, current digital resource protection is often limited to protecting the copyright of the digital resource but ignoring the usufruct. Fine-grained usufruct can be defined as but is not limited to reading, saving and downloading resources. Resource producers can achieve knowledge monetization by selling usufruct.

Therefore, it is urgent to propose a novel and effective method for solving digital resources rights confirmation and infringement tracking. The main challenges here can be summarized as (1) Difficulties in confirming rights: the ownership of digital resources is difficult to track coupled with the fact that infringement is difficult to judge. (2) Difficulties in defining rights: the definition of resource rights is vague, which makes it cumbersome to ensure the enforcement of normal rights. (3) Difficulties in defending rights: the cost of maintaining rights is high and piracy is hard to be proved.

To address these challenges, we present a novel method, which performs cross-platform resource rights confirmation and infringement tracking based on blockchain smart contracts. Blockchains were initially introduced for peer-to-peer Bitcoin payments [1] [11], while smart contracts represent complete programs that run on the blockchain. In contrast with the traditional methods, the advantages of smart contracts are leveraged to ensure the non-mutability of trading logic. Inspired by these advantages, we store transactions on the blockchain and develop smart contracts that focus on the ownership and usufruct of resources [10] [14]. Then, smart contracts can be achieved real-time resource rights confirmation across platforms. For infringement tracking, we reveal the source of resource leakage through extracting digital watermark embedded in the resources and transactions recorded on the blockchain. By combining them [16] digital resource rights confirmation and infringement tracking can be achieved effectively.

Overall, the key contributions of our work are:

- We construct smart contracts to deal with real-time resource rights confirmation across platforms.
- We design and implement the resource rights confirmation and infringement tracking system.

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- Fine-grained division of rights is proposed in our work to further clearly ensure the definition of digital resource rights.
- We foster the study of using the blockchain-based digital watermarking to infringement tracking.

The rest of this paper is organized as follows. We first review related work in Section 2. We then describe the overall architecture of our system in Section 3, and elaborate on the process of resource confirmation and infringement tracking in Section 4. Afterwards, we present the experimental results in Section 5. Finally, we conclude the paper with a discussion of our proposed methods and future work in Sections 6.

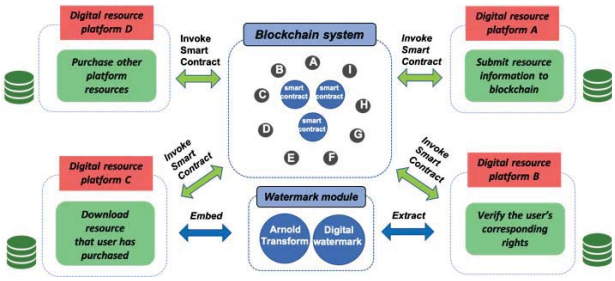

Figure 1 Overview of our proposed system

2 Related Work

The closely related work can be roughly classified into four categories: Smart Contract, Traditional Copyright Protection, Digital Watermarking Technology, and Blockchain-based Copyright Management Methods.

Smart Contract. A smart contract [14], also known as a cryptocontract, is a computer program that directly controls the transfer of digital currencies or assets between parties under certain conditions. Hasan et al. [13] proposed a decentralized PoD (Proof of Delivery) solution for PoD of digital assets, which leverages key features of blockchain and smart contracts to provide immutable and tamper-proof logs, accountability, and traceability. From the perspective of copyright, Bod´o et al. [27] examined the differences between new, smart-contract-based private ordering regime and the fundamental components of copyright law.

Traditional Copyright Protection. On one hand, traditional copyright transactions are generally conducted offline, both parties achieve resource copyright transfer by signing a copyright transaction agreement. On the other hand, content digitalization and high-performance interconnection networks have greatly increased the possibilities to reproduce and distribute digital resources. For either traditional copyright or digital copyright, there are plenty of difficulties in confirming, using, and safeguarding the rights. In [5], Frattolillo presented current trends concerning the most significant solutions to the problem of copyright protection based on Digital Rights Management (DRM) systems [8, 15]. Moreover, watermarking protocols have also been adopted as promising approaches for copyright protection [14, 15].

Digital Watermarking. Digital watermarking is an efficient method for digital access rights management [9]. Many researchers have already worked on the secure and robust digital watermarking scheme in the era of digital information. Liu et al. [20] proposed a new digital image watermarking model based on scrambling algorithm Logistic and RSA asymmetric encryption algorithm that guarantees the security of the hidden data at the foundation of large embedding capacity, good robustness, and high computational efficiency. Kumar N. and Jaishree [12] improved the LSB (Least Significant Bit) watermarking mechanism by using two host images instead of one image to embed the watermark using some logical operations on the bits of the images.

Blockchain-based Copyright Management Methods. At present, there have been efforts that apply blockchain technology to copyright protection, which mainly owes to the development of blockchain technology and the characteristics of blockchain that are exceedingly suitable for copyright protection [5] [11] [18] [19]. Meng et al. [18] presented a novel design scheme of a copyright management system based on digital watermarking and blockchain. In their work, blockchain is used to securely store watermark information and provide timestamp authentication. This scheme combines blockchain and multiple digital watermarks to record copyright information of every copyright owner in the authoring process. Zeng et al. [19] provided an applying pattern of consortium blockchain, then put forward a decentralized architecture of digital image copyright registration based upon the applying pattern, which takes into account instant registration processing and tamper-proof registration information for digital image copyright. However, these methods focus on protecting copyright only by simply adopting the blockchain system.

3 Overview of Our Proposed System

In this section, we present an overview of our proposed system, which consists of three components: blockchain system, digital resource platform, and watermark module. The overall architecture of the whole system is shown in Fig. 1. The blockchain system records all transactions, which ensures the immutability and traceability of transactions. Digital resource platform is usually a centralized website that stores and displays digital resources. Watermark module provides a digital watermark embedding and extracting service.

In the blockchain system, for building a bridge between the blockchain system and digital resource platforms, the API interfaces are offered. Intuitively, smart contracts are constructed on the blockchain system so that digital resource platforms have access to achieve resource interoperability. We develop smart contracts that focus on the ownership and usufruct of digital resources based on Fabric [2] and Composer [3]. During the digital resource propagation, the blockchain system

can invoke the corresponding smart contracts to record changes of ownership and usufruct rights in real-time.

In the digital resource platform, users can upload digital resources such as tutorials, and browse digital resources, and trade ownership or usufruct of resources.

In the watermark module, the digital watermark will offer watermark embedding and extracting service. It employs Arnold Transform, LSB, and DCT to improve the robustness of watermarks. This module will extract watermark to achieve tracking when a tort occurs.

In summary, the overall goal of our system is to achieve rapid resource rights confirmation across platforms, while ensuring the security and credibility of records. Next, we will introduce the details of our method of resource rights confirmation and infringement tracking.

4 Methods

In this section, we elaborate on our method of digital resource rights confirmation and infringement tracking.

4.1 Digital Resource Rights Confirmation

Digital resource rights confirmation is mainly to verify whether a user has the rights to read or download a resource, or whether a user is the owner of a resource. Smart contracts are exceedingly suitable for the verification and protection of digital rights due to its traceable, non-tamperable characteristics. We make use of smart contracts, which designed for real-time resource rights confirmation, to solve the problem of high cost, complex procedures and long cycles in conventional copyright confirmation. Specifically, the smart contracts constructed are as follows:

- We develop a smart contract to submit digital resource information onto the blockchain, which records the unique identification code of resource and its producer in the block upon a resource is uploaded for the first time.
- We then formulate a smart contract to deal with resource ownership or usufruct transaction across multiple resource platforms.
- We also design a smart contract that can verify ownership and usufruct to check whether a user has the rights to access to a digital resource.

All the smart contracts mentioned above are deployed on our blockchain system. We can invoke the corresponding smart contract to record changes in resource rights to achieve real-time validation.

4.2 Infringement Tracking

Infringement tracking is realized by three key steps: (1) when downloading, the watermark module embeds watermarks into the resource,which contains information of the owner, current user, and resource ID. (2) Once a tort happens, the watermarks in the resource will be extracted.(3) Finally, we invoke smart contracts to retrieve on the blockchain system about the transaction chain of the identified user. Next, we will introduce the digital watermarking in 4.2.1, and how to combine the watermark and the blockchain smart contracts in 4.2.2.

4.2.1 Digital watermarking

Digital watermarking [9, 15] is a method of information hiding. The Least Significant Bit (i.e., LSB) [7, 12] algorithm is an algorithm based on the spatial domain, which utilizes a simple embedding method and has a large hidden capacity. The embedded image has almost no visual difference from the original image. We employ LSB algorithm to embed the watermarks that consist of the unique identification code of current copyright owner and current user and resource ID. In order to enhance the security and confidentiality of watermark, Arnold Transform is performed before embedding the digital watermark [6]. Therefore, we further propose a method based on Arnold Transform and LSB digital watermarking algorithm. Moreover, we also apply Discrete Cosine Transform [8] which is one of the most popular techniques for converting a signal into elementary frequency components. DCT-based watermark can modify the coefficients of middle-frequency sub-band so that the visibility of the image will not be affected.

Arnold Transform is the process of scrambling pixel points in an image matrix. This technique is used for image pre-processing, its positive transformation corresponds to the scrambling of the image while the inverse transformation is for recovery.

Positive transformation: We assume the position of any pixel in the matrix as (x, y). Without loss of generality, for a pixel with position (x, y) in the matrix, the pixel point (x, y) is mapped to another point (x', y') by:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} mod\ (N) \tag{1}$$

By this conversion, the polynomial is obtained:

$$\begin{cases} x' = (x + y)\ mod\ (N) \\ y' = (x + 2y)\ mod\ (N) \end{cases} \tag{2}$$

Inverse transform: Equation (1) is equivalent to:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} x' \\ y' \end{bmatrix} mod\ (N) \tag{3}$$

In our practice, we perform Arnold Transform twice in the process of watermark embedding. One to scramble the image before embedding the watermark, and the other to recover the image after embedding.

DCT-Based Algorithm for Watermarking. Discrete Cosine Transform is a common technique used for digital image processing and signal to convert, which is an orthogonal transform. Given a digital image $f(m, n)$, it can be regarded as a two dimensional array of size $M \times N$, the DCT transform on the image is given by

$$F(u, v) = c(u)c(v)\frac{2}{\sqrt{MN}}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f(m, n)$$

$$cos\left(\frac{(2m+1)u\pi}{2M}\right)cos\left(\frac{(2n+1)v\pi}{2N}\right) \quad (5)$$

where

$$c(u) = \begin{cases} 1 & u = 1, 2, \dots, M-1 \\ \frac{1}{\sqrt{2}} & u = 0 \end{cases}$$

$$c(v) = \begin{cases} 1 & v = 1, 2, \dots, N-1 \\ \frac{1}{\sqrt{2}} & v = 0 \end{cases}$$

The image is reconstructed by applying inverse DCT operation according to Eq. (6):

$$f(m,n) = c(u)c(v)\frac{2}{\sqrt{MN}}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}F(u,v)$$
$$cos\left(\frac{(2m+1)u\pi}{2M}\right)cos\left(\frac{(2n+1)v\pi}{2N}\right) \quad (6)$$

4.2.2 Combine Blockchain with Watermarking

Generally, when an infringing act occurs, the tracking mechanism is performed as (1) The Infringement Tracking Center can extract the digital watermarks from the infringed resource to confirm the leaker and original owner. Moreover, in order to ensure the correctness of the watermark information, it can be verified with the records on the blockchain by checking the copyright owner, purchaser, and resource ID. (2) It is necessary to retrieve transaction records to obtain the entire rights transaction chain from the time of resource released to the time of the resource leaked. We query the relevant transaction records on the blockchain and sort the transaction records in time order. Fig. 2 depicts digital resource rights confirmation and infringement tracking based on blockchain and watermarking.

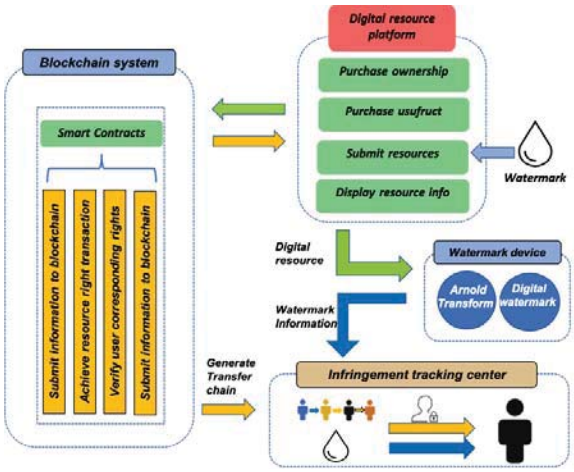

Figure 2 Digital resource rights confirmation and infringement tracking

Specifically, the transaction data recorded in the blockchain is encapsulated as hash value and embedded in the digital watermark, which includes the unique identity of the transaction, the unique identity of both sides of the transaction and the current resource ID. When a user registers or trades copyright, our proposed system automatically interacts with the data in the blockchain and invokes digital watermarking.

On the one hand, by combining the two technologies, we can effectively protect the rights owners. On the other hand, we can prevent the harm of watermarks being stolen. Unlike the traditional copyright protection only using a digital watermark, we embed the resource ID recorded on the blockchain into the resource. As a result, even if the watermark information is stolen, the attacker cannot use the information (e.g., resource ID). Conversely, we can apply it to query all transaction records on the blockchain so that the resource owner can be determined effectively and accurately. Therefore, by combining the watermark information and rights transfer chain, we can accurately and effectively identify the infringing source, which is conducive to deal with infringement disputes.

5 Experiments and Discussion

In this section, we conduct extensive experiments to evaluate the proposed system. We mainly focus to answer the following research questions:

RQ1: How to apply smart contracts to achieve real-time resource rights confirmation during the digital resource dissemination across different platforms?
RQ2: How to implement infringement tracking by combining transactions history recorded on the blockchain and digital watermarking?
RQ3: How effective is our method when compared with existing approaches?
In what follows, we answer the above research questions one by one.

5.1 Study on Rights Confirmation (RQ1)

We empirically study the real-time resource rights confirmation on cross-platform resource transactions. The modules related to resource rights confirmation are:

- Resource submission module. This module is used to submit the digital resource information to the blockchain, where the digital resources include image, text, video, etc.
- Resource display module. It is used to retrieve the recorded resource information from the blockchain and present the data for users to browse.
- Resource rights transaction module. This module records alterations of resource rights, namely usufruct and ownership, on the blockchain in real-time when a transaction occurs.
- Resource rights verification module. This module verifies if a user owns a resource (i.e., ownership) or has the right to read a resource (i.e. usufruct).
- Resource infringement tracking module. This module, when a tort occurs, handles infringement disputes by combining blockchain and watermark.

Submission When uploading a digital resource to the digital resource platform, we call "SubmitResourceInfo" to submit the resource information to the blockchain.

Table I Comparison with existing methods in terms of efficiency, infringement tracking and cross-platform

	Compare Factors		
	Confirmation Efficiency	**Infringement Tracking**	**Cross-platform**
Traditional scheme	Long cycle, low timeliness	Difficult to track	×
Only with watermarking	Long cycle, low timeliness	Trackability, high timeliness	×
Only with blockchain	Real time, high timeliness	Trackability, low timeliness	√
Combine watermark and blockchain (Our method)	Real time, high timeliness	Trackability, high timeliness	√

Moreover, in order to check if the resource platform can effectively obtain resource information from the blockchain system, we request the access interface to gain the resource data by calling "ShowResourceInfo". **Transaction** Considering the diversity of resource rights, we fine-grain the rights as usufruct and ownership. Then, by invoking smart contracts, we achieved record rights alteration in real-time during the resource rights transaction. Fig. 3 shows a request example using a smart contract to trade the ownership of a resource.

```
POST JSON Parameters:
{
    "$class": "org.demo.network.BuyOwnershipTransaction",
    "resource": "org.demo.network.Resource#A-10",   // resource id
    "buyer": "org.demo.network.Customer#A-peng",  //buyer id
}
Curl
curl -X POST –header 'Content-Type: application/json' –header 'Accept:
application/json' –d ' {
    "$class": "org.demo.network.BuyOwnershipTransaction",
    "resource": "org.demo.network.Resource#A-10",
    "buyer": "org.demo.network.Customer#A-peng",
}
```

Figure 3 Response to purchasing the resource ownership

In Figure 3, "$class" denotes business network made up of assets, participants, transactions, etc. "resource" and "buyer" respectively represent the unique identifier of the resource and purchaser. After making a purchase request, smart contracts can automatically record alterations of resource ownership on the blockchain. **Verification** In order to verify whether the user has the corresponding rights to a certain digital resource, we utilize smart contracts to perform verification. When the user expects to access or download one resource across different platforms, it is necessary to invoke the smart contract "CheckUsufructTransaction" to check whether the user has the rights to use the resource. When the user sells or edits a resource, the smart contract "CheckOwnerShipTransaction" can check whether he has the ownership of the resource.

Insight 1: We define the corresponding smart contracts that need to be used on the blockchain for fine-grained digital resource rights. The resource platform automatically invokes the smart contract to rights confirmation. This method effectively implements rights confirmation and guarantees timeliness and security.

5.2 Validation of Infringement Tracking (RQ2)

We now analyze the effectiveness of our proposed infringement tracking method. In order to answer how to implement infringement tracking, we focus on establishing the infringement tracking center to obtain a rights transfer chain and extract digital watermark.

Rights Transfer Chain. In order to track the history records during resource rights transactions, we index the resource unique identifier (e.g., resource ID) and sort it in chronological order to obtain the rights transfer chain. We observe that this way of expanding the rights transfer chain can record the alterations of the rights and the timestamp of each transaction. When a tort occurs, the infringement tracking center can utilize the rights transfer chain to confirm the resource owner and reveal the user that leaks the resource.

Digital watermark. We investigate two kinds of watermark algorithms, namely LSB with Arnold Transform and DCT. In our experiment, we embed a digital watermark in an image, where the embedded watermark contains the unique identification code of current copyright owner and current user and the resource ID. We would like to point out that the digital watermark embedding is automatically executed by invoking the digital watermark tool when the resource is distributed. We present the effects of our watermark tool in Fig. 4, where the left figure shows the original image, the middle and right figures show the scrambled image and watermarked image, respectively.

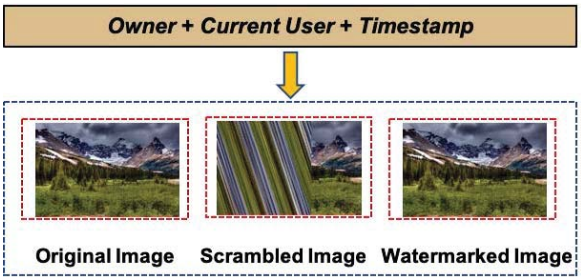

Figure 4 Comparison before and after watermarking

Insight 2: We employ the above two methods to deal with the infringement. The rights transfer chain and digital watermarking are two complementary methods. Combining them can improve the efficiency and accuracy of infringement tracking.

5.3 Comparison with Existing Methods (RQ3)

After empirically analyzing the effectiveness of real-time rights confirmation and infringement tracking, we now focus on performance comparison of our system w.r.t. existing methods. Among the possible comparison methods, we consider the traditional scheme (transaction by signing papers), and the work proposed in [9] and [4]. O'Ruanaidh et al. [9] employ watermark, while Holland

M et al. [4] only uses blockchain. These methods are selected because they are of different types and are closely related to our work.

Table I depicts concrete comparison results over existing methods. In terms of confirmation efficiency, traditional scheme suffers from a long cycle and low timeliness. In contrast, our method has the advantages of real-time confirmation. Moreover, the traditional method has difficulties in implementing infringement tracking. Another important observation is that the blockchain-based approaches can better deal with cross-platform rights confirmation. Further, as an important basis, we make some objective evaluation to compare with the traditional centralized online platform.

Traditional centralized online platform VS Platform based on blockchain and digital watermark First of all, the traditional centralized online trading platform is only to provide an online information exchange platform, and the steps that are truly related to the copyright transaction are all completed by the parties to the transaction. Second, due to the vague definition of traditional resource rights, copyright cannot be fully presented on the platform and is easily vulnerable to infringement. Therefore, the traditional copyright trading platform still has its limitations, resulting in poor user experience and time-consuming. In contrast, with the blockchain, we can directly record copyrights. Real-time resource rights confirmation through smart contracts, the rights holders corresponding to each resource are recorded in the chain, and the non-tamperable of the blockchain guarantees its authenticity and accuracy. In addition, through the watermark information embedded in the resource, we can query all the transactions recorded on the blockchain accordingly, which contributes to the infringement tracking.

Insight 3: Combining with smart contracts and digital watermarking is more effective in terms of digital resource rights confirmation and infringement tracking. The digital watermarking module is able to identify the infringer, while the smart contracts are able to ensure the immutability of the key information of rights transaction. Complementing them with each other provides a new way of thinking for future copyright protection.

6 Conclusions

In this paper, we present a resource rights confirmation and infringement tracking approach based on blockchain smart contracts. We subdivide digital resource rights as ownership and usufruct. We show an effective method of rights confirmation and infringement tracking for that combines rights transfer chain and digital watermark. Extensive experiments demonstrate the efficiency and effectiveness of our method. For future work, we will study smart contracts that can handle more subdivided rights. Moreover, for digital watermark algorithms, we will investigate more efficient digital watermark algorithms that combine better with blockchain.

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