On the Security of a Revised Fragile Watermarking Scheme

Daniel Caragata

Universidad Tecnica Federico Santa Maria, Departamento de Electronica
daniel.caragata@usm.cl

Abstract

This paper analyzes a revised fragile watermarking scheme proposed by Botta et al. which was developed as a revision of the watermarking scheme previously proposed by Rawat et al. A new attack is presented that allows an attacker to apply a valid watermark on tampered images, therefore circumventing the protection that the watermarking scheme under study was supposed to offer. Furthermore, the presented attack has very low computational and memory requirements.

Keywords: multimedia security; fragile watermarking; cryptanalysis; content integrity.

1. Introduction

In recent years we have witnessed an impressive increase in the quantity of digital images being taken and transmitted, mostly due to the development of affordable digital cameras and to the high penetration rate of the Internet. This context has lead to an augmented effort of the scientific community to develop tools that protect digital images. One of these tools is fragile watermarking, which is supposed to protect the integrity and authenticity of digital images: a watermark is inserted in the image such that there are no perceptible changes to the human eye, but that it is possible to detect any malicious changes to the image.

Various watermarking schemes have been proposed that work either in the pixel domain [1,2,3] or in the transform domain [4,5,6,7]. As it is normal in cryptography, a lot of effort has also been put in attacking some of the proposed watermarking schemes [8,9,10].

Rawat et al. have proposed a new fragile watermarking, [3], that embeds the watermark in the LSB of every pixel. However, it was soon attacked by Teng et al. [10] as well as by Botta et al. [8] and both papers have also presented revised versions of the algorithm. Teng et al.’s proposed fragile watermarking embeds a watermark, that is also a function of the pixel content, in one of the three least significant bits. A chaotic function is used to determine the exact
location of the watermark. Botta et al.’s fragile watermarking scheme generates a watermark that is a function of the pixel value, but always embeds it in the least significant bit of the pixel. This paper studies the security of Botta et al.’s fragile watermarking algorithm and shows that it is relatively easy to break.

The rest of this paper is organized as follows. In Section 2 we present the cryptographic perspective that we will use for the cryptanalysis as well as the different attack models, in order to better understand the cryptographic context of the attack we propose. Section 3 presents the details of Botta et al.’s fragile watermarking and an example of its use. In Section 4 we describe the proposed attack and we present one successful implementation of the attack. Section 5 concludes our work.

2. Cryptographic security

Fragile watermarking is a cryptographic primitive because it tries to protect the integrity of some data, i.e. the image, in an adversary setting [11]. Therefore, in order for a fragile watermarking algorithm to be considered secure, it must respect Kerckhoffs Principle [12, 13]. This means that the algorithm must be secure in the worst case scenario: when the attacker knows all the details of the algorithm except the secret key that was being used. Also, the algorithm must be secure in all of the 4 most common models of attack [11]:

- **ciphertext only model**: the attacker only has access to some protected data.
- **known plaintext model**: the attacker has access to some protected data as well as the corresponding unprotected data.
- **chosen plaintext model**: the attacker is able to obtain the corresponding protected data of some (unprotected) data he chooses.
- **chosen ciphertext model**: the attacker is able to submit some protected data to the cryptographic primitive under attack and can obtain the corresponding unprotected data or the verification of its integrity.

In the above enumeration we have used the terms ”protected data” and ”unprotected data” in order to make the definitions as broad as possible. For example, if the cryptographic primitive under study is an encryption algorithm, the ”protected data” is the ciphertext, while the ”unprotected data” is the plaintext.

This paper will present a chosen plaintext attack on a recently proposed fragile watermarking algorithm. In the case of fragile watermarking, the term ”protected data” refers to the watermarked image, while the term ”unprotected data” refers to the unprotected image, i.e. the image prior to the embedding of the watermark.
3. Revised fragile watermarking algorithm

Botta et al. have recently proposed a fragile watermarking algorithm [8] based on the cryptanalysis of Rawat et al’s fragile watermarking algorithm [3]. The proposed fragile watermarking algorithm embeds the watermark as follows:

E1. The original image, \( I_h \), of size \( m \times n \) is scrambled using Arnold cat map \( k \) times, to obtain the scrambled image \( I_s \).

E2. A chaotic sequence, \( C \), is generated using logistic map [15]. The sequence is of same size as the image \( I_h \). Further, the values of \( C \) are rounded off to obtain a bit sequence.

E3. For every pixel \( p_i \), of coordinates \( x \) and \( y \), the binary chaotic watermark \( W_c(x, y) \) is computed as:

\[
W_c(x, y) = \text{parity}(W(x, y) \oplus C(x, y) | MAC_k(p_i) \times x \times y) (1)
\]

where ”parity” means the number of bits with value one, \( W \) represents the original watermark, MAC is a Message Authentication Code and ”\|” means concatenation.

E4. Embed \( W_c \) in the LSB (Least Significant Bit) of every pixel of \( I_s \).

E5. To obtain the watermarked image, \( I_w \), Apply Arnold cat map \( T \cdot k \) times, where \( T \) is the period of Arnold cat map.

For watermark extraction from a watermarked image, \( I_w \), the following steps need to be performed:

D1. The watermarked image is scrambled applying Arnold cat map \( k \) times, to obtain the image \( I_{ws} \).

D2. The binary chaotic sequence \( C \) is computed exactly the same way as for the embedding process.

D3. For every pixel \( p_i \), of coordinates \( x \) and \( y \), an expected watermark is computed as:

\[
W_e(x, y) = \text{parity}(W(x, y) \oplus C(x, y) | MAC_k(p_i) \times x \times y) (2)
\]

D4. A new image, \( I_{temp} \), is constructed as the absolute difference between the expected watermark, \( W_e(x, y) \) and the LSB of every pixel of \( I_{ws} \).

D5. The tampered regions are detected applying Arnold cat map \( T \cdot k \) times on \( I_{temp} \).

We have implemented Botta et al’s watermarking algorithm and we present the results in Figure 1.

Figure 1a shows the original image, which has been watermarked with the watermark image shown in Figure 1b. The resulting watermarked image is presented in Figure 1c. We have tampered the watermarked image by inserting a boat on the lake, as shown in Figure 1d. Then, we have applied the watermark detection and we have obtained the tampered regions presented in Figure 1e. We can conclude that the watermarking algorithm performs as expected.
Figure 1: Botta et al’s fragile watermarking algorithm
4. Cryptanalysis

In this section we will present an attack against Botta et al’s fragile watermarking scheme. We will first describe the attack and then show the results of its implementation.

4.1. Attack description

The attack presented in this paper falls under the chosen plaintext model, i.e. the attacker needs to be able to obtain the watermarked version of some images he chooses.

The watermarking algorithm under study is supposed to be secure because the embedded watermark in every pixel is a function of the secret key, the 7 most significant bits of the pixel and of the pixel coordinates. However, this means that if a pixel in a given location in the image, \((x, y)\), has the same value in different images, the same watermarking bit will be embedded. Moreover, since the LSB of the pixel is used to embed the watermark, only \(2^7 = 128\) possible values exist for every pixel position.

Therefore, the attacker needs to know the watermarking bit \(W_c(i)\) for every pixel \(p_i\), of coordinates \(x\) and \(y\). For this, he will run the watermarking algorithm 128 times and will store the LSB plane of the watermarked image. With this information, the attacker will construct a three dimensional look-up table whose search fields will be the two coordinates, \((x, y)\), and the value of the 7 most significant bits of the pixel, and whose values will be the corresponding watermarking bit \(W_c(i)\). This look-up table requires \(m \times n \times 128\) bits storage space.

Once the attacker has constructed the above mentioned look-up table, he can apply a valid watermark on any image. Therefore, the attacker has the ability to circumvent the protection offered by the watermarking algorithm under study.

4.2. Implementation results

We have implemented the proposed attack and we were able to apply a valid watermark on a tampered image, as shown in Figure 2

Figure 2a shows the image watermarked with the watermark image presented in Figure 2b. We have tampered this image by inserting a boat in the lake and we have used the attack presented in the previous subsection to apply a valid watermark on the tampered image. The resulting image is shown in 2c.

When running the watermark detection algorithm, the LSB of all the pixels will be equal to the expected watermark computed using Eq. 2, therefore the watermarking algorithm will not detect that there are tampered regions, as shown in Figure 2d.

5. Conclusions

This paper has analyzed the security of a recently proposed fragile watermarking scheme and has presented an attack that is capable to circumvent the
Figure 2: Unsuccessful detection of tampered image
protection that the watermarking scheme under study is supposed to offer. Furthermore, the computational complexity of the attack is very small, only 128 runs of the watermarking scheme are needed. Also, the memory requirements are very limited, only $m \times n \times 128$ bits are needed. We have abstained ourselves from proposing an improvement to the scheme because we feel there are a lot of available watermarking schemes and that the scientific community would benefit more from a thorough analysis of the already proposed watermarking schemes.

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