Watermarking 2D/3D Graphics for Copyright Protection

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ABSTRACT

In recent years the importance of 2D maps and 3D models has grown significantly, especially due to the popularity of map data over the web and computer graphics used in entertainment and e-commerce applications. In this paper we will review the concept of image watermarking, and extend it to 2D/3D vector data. We will present a number of watermarking algorithms for 2D electronic maps and 3D wire-frame models. We show that invisible watermarks can be added to 2D/3D data and detected reliably. The watermarks can be designed to be robust to quantization of the vector data and several other hostile attacks.

1. INTRODUCTION

Digital contents, such as pictures, music, movies, digital maps, etc., have become very popular in the last decade. In the mean time, the development of the Internet and related technologies have made digital contents to be easily copied, modified and distributed. The misuses of these technologies may violate the legal rights of the content providers or customers. Therefore, research on digital rights protection is becoming more important and urgent. Digital watermarking, no doubt, is one of the successful solutions to the copyright protection problem.

An invisible digital watermark containing owner descriptions, customer identifications or tampering detection information, can be embedded into digital contents by some watermarking algorithm. Whenever necessary, the original embedded watermark can be extracted form the digital contents for authentication or tracing of any abuses. Surely, a watermarking algorithm must be robust against most kind of attacks to ensure the reconstruction of the original watermark. In the past few years, many watermarking algorithms for video or audio have been proposed while there are very little research addressing watermarking algorithms for 2D digital maps, 3D model data. In this paper, we will provide an overview of watermarking algorithms for 2D vector maps or 3D wire-frame models.

In Section 2, we will review the basic concept of digital watermarking. We will explain how the basic concept originally applied to audio or images can be extended to 2D/3D vector data as well. In Section 3, we will present a number of watermarking algorithms for 2D vector map data. In Section 4, we will discuss a number of watermarking algorithms for 3D wire-frame model data.

2. CLASSIC WATERMARKING

Most of watermark research in literature focuses on images, video or audio [1-17]. In general, a watermarking system contains watermark generation, watermark embedding and watermark detection algorithms.

In most watermark generation algorithms, a pseudo random bit sequence is first generated with a chosen seed, which may be viewed as the key of the watermark system. Then, an "exclusive OR" operation is taken between the pseudo random bit sequence and the information bit sequence, which represents the information to be embedded, e.g., the ownership information, to obtain the resulting bit sequence called the *watermark*. In the watermark embedding algorithm, the watermark is added into the spatial domain, time domain or frequency domain of the original image/video/audio data as shown in ***Figure 1***. Given some image/video/audio data, the detection algorithm then calculates some form of correlation between the data and the watermark to verify if the data contains the watermark or not as shown in ***Figure 2***.

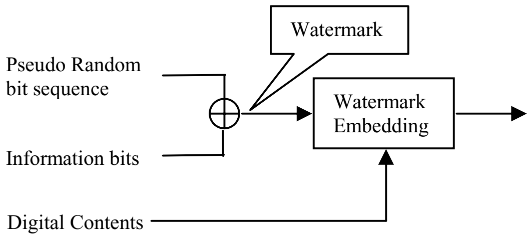

Figure 1. Watermark embedding

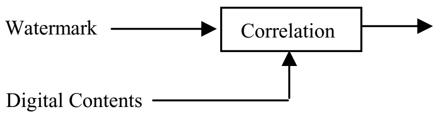

Figure 2. Watermark Detection

Usually, for the purpose of storage or bandwidth saving, images/video/audio are compressed before they are stored or transmitted. Obviously, a lossy compression algorithm may affect the original embedded watermark. To reconstruct the embedded watermark correctly, the watermarking algorithm must be robust against the compression process. Alternatively, the watermarking embedding can be performed after the compression.

As a note, image, video and audio data are almost never revised after they are produced, watermarked and saved. Thus, classic watermark algorithms do not need to consider the robustness under revisions. Watermarking algorithms for 2D/3D vector data, however, need to have such considerations.

3. 2D VECTOR MAP DATA

Unlike image/video/audio data, which contain raster data of the spatial or temporal domain, vector maps are constructed by coordinates of points, polylines and polygons. Therefore, most classic watermark embedding algorithms and watermark detection algorithm can not be applied directly to vector maps. On the other hand, watermark generation algorithms of image/video/audio data can be easily used for vector map data.

Solachidis, Nikolaidis and Pitas [18, 19] proposed the Fourier descriptors for watermarking of vector graph images. The 2D coordinate (x,y) of each vertex is mapped to a complex value $z = x + yi$. After that, the Fourier transform can be applied to the vertices of a polyline or polygons to obtain the Fourier descriptors. The watermark can then be added to the Fourier descriptors and can be detected by evaluating the correlation between the embedded watermark and the watermarked Fourier descriptors. The paper also mentioned the influences on the Fourier descriptors by some geometric distortions of the vertices, such as translation, rotation, mirroring, etc. The interesting influences are helpful for designing a robust algorithm with Fourier descriptors. Kitamura, Kanai and Kishinnami [20] also proposed a copyright protection algorithm for vector maps based on the Fourier descriptors concept.

Ohbuchi, Ueda and Endoh [21] proposed a watermarking algorithm that embeds each bit by displacing the vertices in a block. A vector map is divided into some rectangular blocks of adaptive sizes according to the density of vertices. After the block division is done, vertices in a block are sequentially added or subtracted by a small amount according the corresponding embedded bit being 1 or 0. To extract the embedded watermark, a preprocessing algorithm is applied to the watermarked map data to detect vertices that have been removed or added to the watermarked map data. After that, the watermarked map is compared to the map before watermarking for extracting the embedded bits. The robustness of the algorithm can be increased by repeating the embedded bits. Simulation results of the bit errors under the different kinds of attacks are also analyzed in this paper.

Hwan, Kab and Jong [22] proposed another vector map watermarking algorithm by moving vertices in a block for embedding each bit. First, the vector map is divided into blocks with the same area. Vertices in a block are moved to the upper or lower triangular region depending on the embedded bit of the watermark. The embedded watermark can be extracted simply by determining in which triangular area that the corresponding vertex lies.

Barni et al. [23] proposed a text-based geometric normalization method for watermarking of digital maps. By the normalization method, the robustness of any watermarking algorithm can be ensured. The normalization is done by rotating the text within the map to a given orientation, extracting the oriented text and scaling the text. After the normalization is performed, a watermark embedding or detection algorithm can be applied to the normalized map and the robustness of the watermarking algorithm is ensured. Unlike the feature-based normalization method, which suffers from feature changes caused by watermarking or other attacks, the proposed normalization algorithm shows much better results.

4. 3D MODEL DATA

The importance of 3D models has grown significantly in the past decade, especially due to the popularity of computer graphics in entertainment and e-commerce applications. As a result, many researchers have tried to extend techniques traditionally used for watermarking images to watermarking 3D wire-frame models. We will discuss three algorithms [24], [25], [26].

As mentioned in Section 2, the same watermarking technique can be applied to many types of data. However, 3D models, composed of vertices and edges, have a very different data structure. For example, re-ordering the vertices of a 3D model does not affect the model at all, while swapping audio samples or image pixels changes the signal completely. The non-unique ordering of vertices of a 3D model hence makes it very difficult to watermark.

In [24], the authors presented a scheme for progressively transmitting a 3D model, vertex by vertex, over the network. In addition to progressive transmission, the scheme also provides a method of uniquely ordering the vertices of a 3D model into a 1D sequence. Furthermore, such ordering is invariant to translation, rotation and scaling of the model. It is therefore possible to embed a pseudo-random sequence, or the watermark, into the 1D sequence formed by some characteristic of the ordered vertices, such as the distance between the vertex and the mean of the neighboring vertices. Hence, vertex ordering effectively makes watermarking a 3D model the same as watermarking any 1D sequence. However, if any attack would change the ordering of the vertices, then it would defeat the watermark. To work around this problem, the vertex sequence can be segmented into blocks, and then the watermark sequence is embedded block by block. In this case, as long as the attack does not change the vertex order beyond the block boundary, the watermark can still be detected. Plus, the strength of the watermark can be adjusted for each block to make the watermark less visible. Experiment results show that this watermarking scheme is reliable while not affecting the perceptual quality of the models too much. This algorithm also allows a large number of different watermarks to co-exist, simply by varying the pseudo-random seed.

In [25], the authors propose the “triangle similarity quadruple embedding” approach. The algorithm selects a group of 4 adjacent triangles, modify them so that they become similar. The detection is then done through verifying such similarity in a given 3D model. This algorithm is simple and resistant to uniform scaling, translation, rotation, local deformation resection. However, it is susceptible to randomization, affine transforms, and re-meshing.

In [26], the authors propose to embed the watermark information in the *spectral* domain, similar to the spread-spectrum technique used to watermark audio signals and images. While the spectral domain analysis or 1D/2D signals can be done with the Fourier transform, the spectral domain of 3D models need to be defined differently. The authors present a way to construct a set of scalar basis functions over the vertices, by applying multiresolution analysis to the 3D model. After that, they embed watermark information into these basis functions. The watermark is embedded by perturbing vertices along the direction of the surface normal, weighted by the basis functions. In order to deal with attacks such as model simplification that may modify the connectivity of the vertices, the authors propose an optimization technique to resample the attacked model using the original model connectivity. Results show that doing so makes the watermark resilient to translation, rotation, uniform scaling, cropping, smoothing, simplification, resampling, noise attack, and embedding of another watermark. One weakness of this scheme is that it is a *private* watermarking scheme. That is, the detector needs to know the original model in order to detect the watermark.

5. CONCLUSION

In this paper, digital watermark algorithms for 2D vector map data and 3D model data were reviewed. These algorithms are robust against most kinds of attacks to ensure the integrity of the watermark information. Watermarking protects such 2D/3D intellectual property with a unique secret code or a special graphic pattern. The code can be reliably detected for the purpose of claiming ownership against illegal uses.

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