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A watermarking for 3D mesh using the patch CEGIs

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Abstract

This paper proposes 3D mesh watermarking using the CEGI distribution that is robust against mesh simplification, cropping, vertex randomization, and rotation and does not require the original model for realignment or extracting the watermark. In the proposed algorithm, a 3D mesh model is divided into patches using a distance measure, then the watermark bits are embedded into the normal vector direction of the meshes that are mapped into cells with large complex weights in the patch CEGIs. The watermark can be extracted based on two watermark keys, the known center point of each patch and a rank table of the cells in each patch. In a rotated model, the realignment process is accomplished using the above watermark key instead of the original model before extracting the watermark. Experimental results verified the robustness of the proposed algorithm based on watermark extraction after various types of attack.

Keywords: 3D mesh; Blind watermarking; CEGI

1. Introduction

Digital media, such as images, audio, and video, can be readily manipulated, reproduced, and distributed over information networks. Therefore, a lot of research has been carried out to protect the copyright of digital media, and digital watermarking is one such copyright protection technique [1,2]. Recently, 3D graphic models, such as 3D geometric

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CAD data, MPEG-4, and VRML, have become very popular, leading to the development of various 3D watermarking algorithms to protect the copyright of 3D graphic models [3–14].

3D graphic models have different characteristics compared to still images and video. In contrast to the depiction of images and video by pixel intensity in a fixed 2D spatial and temporal domain, 3D graphic models are usually represented by a mesh defined by the coordinates and connectivity of vertices in a 3D spatial domain [15] what we refer to as 3D mesh models. The vertices are enumerated in order, which is variable and not fixed, while the connectivity is the order information for the enumerated vertices that comprise the mesh. 3D graphic models can be easily modified by means of a geometrical operation that changes the vertex coordinates or topological operation that changes the connectivity of vertices. Plus, there is no unique means for representing a 3D graphic model, as it can be depicted as various mesh models consisting of different coordinates and vertex connectivities. Furthermore, to increase the rendering speed on the Web, the number of vertices in a 3D graphic model can be reduced by mesh simplification while preserving the shape of the model. Therefore, the above characteristics must all be carefully considered for watermarking to be robust.

Ohbuchi et al. proposed an algorithm that embeds a watermark in the mesh spectral domain based on the connectivity of the vertices [4], while Praun et al. proposed an algorithm that provides a scheme for constructing a set of scalar basis functions over the mesh vertices on the basis of the spread-spectrum principle [5]. Both of these algorithms are robust against the various geometrical and topological attacks, yet if the mesh connectivity is altered by remeshing or mesh simplification, these algorithms require the suspect mesh model to be resampled for the watermark extraction to obtain the geometry of the original mesh model with a given connectivity information. Kanai et al. proposed a watermarking algorithm for 3D polygons using multiresolution wavelet decomposition [6]. Yet, the application is still restricted to a certain topological class of mesh, as the wavelet transform can only be applied to 4-to-1 regular subdivision connectivity schemes. Benedens also proposed an algorithm that embeds a watermark by modifying the mesh normal distribution that is included in randomly selected bins of the EGI, which is the factor that determines the shape of a 3D object [7,8]. As such, the mesh normal distribution used by Benedens is very good at satisfying the above requirements and expressing the shape characteristics of a 3D mesh. However, in the case of partial geometric deformation, such as cropping, the meshes included in these directional bins disappear along with the embedded watermark. Therefore, mesh watermarking is required that is not only robust against remeshing, mesh simplification, and cropping, but also allows watermark extraction without the original mesh model.

Accordingly, the current paper proposes blind watermarking for 3D mesh models using patch CEGIs. The CEGI concept extends the EGI representation by adding the normal distance of the mesh to the origin as a phase component of the complex weight. As such, this allows the pose of the 3D mesh to be extracted and also distinguishes a convex model from a non-convex model, whereas the EGI representation cannot make such a distinction. Therefore, these additional characteristics allow for effective selection of a watermark embedding location that is robust against various attacks. First, the meshes of a 3D mesh model are clustered into certain patches using a distance measure. The patch number clustered in a model is determined by the magnitude distribution of complex weight in CEGI