A Survey on Recent Patents in Texture Synthesis

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Received: August 15, 2011; Accepted: August 24, 2011; Revised: September 15, 2011

Abstract: Textures have been a research focus for many years in human perception, computer graphics and computer vision. Recently, research activities in this area emphasize on texture synthesis. Given one or more example textures, a texture synthesis algorithm generates a new one bearing the same visual characteristics. The synthesized texture can be made of arbitrary size specified by the user. It can be used in many fields such as computer animation, virtual reality, data compression, non-photorealistic rendering and so on. In this paper, the basic concepts of texture and the development process of texture synthesis techniques are introduced first. Then the recent key patents on texture synthesis schemes are reviewed. Finally, this paper points out future works in this area.

Keywords: Anisometric synthesis, neighborhood matching, texture synthesis.

1. INTRODUCTION

"Texture" is an expression with multiple meanings. In describing the objects in the real world, the "texture" is synonymous with the surface's material structure, including a number of psychological parameters to describe the feelings characteristics: coarseness, contrast, orientation, line-likeness and roughness, etc. In image processing, all the repeated elements of the digital image can be called "texture". In the three-dimensional graphics rendering, texture is a digital image. Textures are mapped to the surface of 3D models, giving the models a more realistic look. In computer graphics, we are dealing with the third which are used for realistic image rendering.

In reality there are many ways to obtain the textures, such as hand-painted patterns and scanned photos. Handpainted patterns have a good sense of beauty, but to make them as realistic as a photograph is difficult. Scanned photos is realistic, however, there will be obvious cracks or repeated when they are directly used for texture mapping due to size constraints. Recently, research activities in this area emphasize on texture synthesis which is defined in [1] as" a texture synthesis method starting from a sample image and attempts to produce a texture with a visual appearance similar to that sample".

Texture synthesis is an effective method of generating textures and can be used to synthesize textures of any size, so it can largely avoid visual repetition. Also, if the boundary conditions are adjusted correctly, it will be able to generate good visual texture. The goal of texture synthesis can be summarized as: Given a texture sample Fig. (**1**), synthesize a new texture that, when perceived by a human observer, appears to be generated by the same underlying process Fig. (**1b**).

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In this paper, we will first introduce related works on texture synthesis algorithms. Then we review the recent authorized patents in this area and the texture synthesis-based applications such as video encoding, texture compression, etc.

2. SYNTHESIS TEXTURES

The following summarizes the previous work. The main body of texture synthesis algorithms could be classified into the procedural-based approach and the exemplar-based one. Stochastic texture synthesis and specific structure texture synthesis are procedural-based approaches, while pixel-based, patch-based and tile-based texture synthesis algorithms are exemplar-based means.

Stochastic texture synthesis algorithms randomly select the color of each pixel for texture synthesis, and the results are controlled only by a few basic parameters, such as minimum brightness, the average color, contrast and so on. The three-dimensional noise model [2] proposed by Perlin is typical of such an algorithm, which can be used for synthetic marble, wood and other textures. Worley [3] improved Perlin noise model. He proposed a new class of texture basis function which can be used for synthesis of rock, water and other textures. Stochastic texture synthesis algorithm is suitable only for random strong texture, as it does not consider the structural information.

Specific structure texture synthesis algorithms use pre-set procedures and parameters to synthesis images. Each program and parameter applies only to a particular type of structure texture. A variety of mathematics, physics, biological models have been used, such as fractals, Fibonacci series, cell growth model. As specific models only reflect the characteristics of a particular structure of the texture, these algorithms are often specific for a certain type of texture and design. Researchers have designed a variety of specific texture synthesis algorithms for the appearance of plants and animals. Turk [4] used reaction - diffusion system to synthesize animal fur patterns. Lefebvre *et al*. [5] used a semi-

1874-4796/12 $100.00+.00

(a) Texture (b) Synthesis result

Fig. (1). Texture synthesis. Given an example texture (**a**), the goal is to synthesize a new texture that looks like the input (**b**). The synthesized texture can be arbitrary size specified by the user.

empirical system to synthesis bark texture. Desbenoit *et al*. [6] proposed an open diffusion-limited model for lichen. Since algorithm of this type are designed for particular patterns, so for the same or similar structure, these methods can often achieve excellent results. However, these algorithms do not suit for multiple types texture synthesis, such as a high quality brick wall texture synthesis algorithm in dealing with gravel roads is difficult to get high-quality texture synthesis results.

Pixel-based algorithms are the simplest but the most effective general-purpose texture synthesis algorithms. They usually search and copy the pixels from the exemplar with the most similar neighbors. The non-parametric sampling algorithm proposed by Efros [7] and Leung, the natural texture synthesis algorithm proposed by Ashikihmin [1], and Hertzmann [8] image analysis, etc., are typical pixel-based texture synthesis algorithms. Pixel-based texture synthesis algorithms generally use approximate nearest neighbor (Approximate Nearest Neighbor) method in time-consuming steps to accelerate the search.

Patch-based texture synthesis algorithms are developed based on the pixel-based ones. The main difference between the two is pixel-based algorithms search and copy operation by pixels, while the patch-based algorithm search and copy different texture offset patches in exemplar for synthesis. Typical examples of such algorithms are patch-based real-time texture synthesis algorithm proposed by Liang *et al*. [9], image quilting proposed by Efros and Freeman [10], Graph-cut proposed by Kwatra *et al*. [11] and so on. Compared with the pixel-based texture synthesis algorithm, patch-based texture synthesis algorithms are usually better quality, more efficient.

Tile-based algorithms tile the input images (or some small patches in them) in a certain order to generate larger images. Unless the input images meet certain special constraints, this synthetic result is usually far from ideal, and the edges of the seams will be quite obvious. An improved method is Guo *et al*.'s [12] chaos mosaic algorithm which randomly selects the size and location of the cover sheet for secondary coverage to resolve a high degree of repetitive problems, and then use filters to remove seams, but this joint approach will result in image fuzzy. Cohen *et al*. [13] proposed a method of using Wang-tiles for texture synthesis, but Wang-tiles are required to generate the samples for 45-degree rotation, for part of the texture will cause an unnatural effect. To solve this problem, Ng *et al*. [14] employed ω – tiles instead of Wang-tiles. This method is extended on both patterns and qualities in [15]. Lagae and Dutre [16] proposed a deformation of Wang-tiles to generate overlay sets without the need for sample rotation. Dong *et al*. [17] improved the synthesis quality of Wang tiles by using Genetic Algorithm for sample patches selection. For some texture, especially structural strong texture, the results of tile-based methods are not as good as patch-based algorithms, but after calculating the pre-generated cover sheet sets, the tile-based algorithms can generate large textures in real-time thus they are superior to patch-based algorithms in efficiency.

For some special textures, novel techniques have also been presented. Zhang *et al*. [18] present an approach for decorating surfaces with progressively-variant textures. Liu *et al*. [19] present techniques to analyze and synthesize near-regular textures through multi-model deformation fields. Eisenacher *et al*. [20] combine a simple user interface with a generic per-pixel synthesis algorithm to achieve high-quality synthesis from a photography. Dong *et al*. [21] present a novel texture synthesis scheme for anisotropic 2D textures based on perspective feature analysis and energy optimization.

3. PATENT REVIEW RELATING TO TEXTURE SYNTHESIS

In this section, we review recent and important patents and inventions or methodologies that involve texture synthesis-based applications in the last two years. The subsections that follow discuss the most relevant patents.

3.1. Synthesis of Advecting Texture Using Adaptive Regeneration

Patent US7643034 [22] claims an adaptive texture regeneration method and system for generating a sequence of images over time (an animation sequence) that gives the appearance of texture flowing over a surface. The adaptive texture regeneration method and system helps keep synthesized texture flow over a surface from becoming so distorted such that it no longer resembles the original exemplar. This is achieved in part by using pixel coordinates instead of colors. By using pixel coordinates, distortion of the texture can be measured. Based on this distortion measurement, the texture can be adaptively regenerated if necessary. The distortion measurement of the texture is measured and compared to a distortion threshold. If the measured distortion does not exceed the threshold, then the current synthesized texture is retained. On the other hand, if the measured distortion exceeds the threshold, the current synthesized texture is regenerated.

3.2. Anisometric Texture Synthesis

Patent US7733350 [23] claims an anisometric texture synthesis system and method for generating anisometric textures having a similar visual appearance as a given exemplar, but with varying orientation and scale. This variation is achieved by modifying the upsampling and correaction processes of the texture synthesis technique using a Jacobian field. The modified correction process includes accessing only immediate neighbors of a pixel instead of non-local pixels. This constraint that only immediate neighbors be used also allows the generation of seamless anisometric surface textures. This is achieved by using indireaction maps containing indirection pointers that are used to jump from a set of pixels outside the boundary of a texture atlas chart to another chart. The system and method also includes an anisometric synthesis magnification technique that uses a Jacobian field to modify the magnification step of a synthesis magnification scheme and account for anisometry.

3.3. Sub-pass Correction Using Neighborhood Matching

Patent US7817160 [24] claims a method and system for synthesizing texture using a preprocessed exemplar image and a neighborhood-matching per-pixel texture synthesis correction technique. The sub-pass correction system and method alters pixel coordinates to recreate neighborhoods similar to those in the exemplar image. In the context of parallel texture synthesis, instead of synthesizing all pixels of an image simultaneously, the sub-pass correction system and method allows neighbors to be corrected in different subpasses. Each pixel, therefore, benefits from the correction of some of its neighbors in previous sub-passes. This reduces the required number of global correction passes to obtain good synthesis results Generally, one or more correction passes are performed, with each correction pass divided into a plurality of correction sub-passes. A number of pixel coordinates are corrected in parallel during each of the correction sub-passes.

3.4. Texture Synthesis Using Dimensionality-reduced Appearance Space

Patent US7817161 [25] claims a dimensionality-reduced appearance space system and method that transforms an exemplar image from a traditional three-dimensional space of pixel colors to a low-dimensional Euclidean space of appearance vectors. The transformation of an exemplar is a preprocessing step, and the transformed exemplar becomes the starting point for high-quality texture synthesis. The exemplar transformation begins by computing a high-dimensional appearance vector using one or a combination of several attribute channels. These attribute channels provide additional information to further distinguish exemplar pixels from each other. These attribute channels includes spatial pixel neighborhoods, feature distance, and radiance transfer information. Dimensionality reduction is applied to the resulting high-dimensional appearance vector to generate the transformed exemplar in low-dimensional Euclidean appearance space. Because much of the information contained in the high-dimensional appearance vector is redundant or coherent, dimensionality reduction can be applied to drastically reduce the dimensionality of the appearance vector with little loss of information.

3.5. Inverse Texture Synthesis

Patent US7973798 [26] claims a method named “texture generator” which uses an inverse texture synthesis solution that runs in the opposite direction to traditionally forward synthesis techniques to construct 2D texture compactions for use by a graphics processing unit (GPU) of a computer system. These small 2D texture compactions generally summarize an original globally variant texture or image, and are used to reconstruct the original texture or image, or to resynthesize new textures or images under user-supplied constraints. In various embodiments, the texture generator uses the texture compaction to provide real-time synthesis of globally variant textures on a GPU, where texture memory is generally too small for large textures. Further, the texture generator provides an optimization framework for inverse texture synthesis which ensures that each input region is properly encoded in the output compaction. In addition, the texture generator also computes orientation fields for anisotropic textures containing both low- and high-frequency regions.

3.6. Motion Field Texture Synthesis

Patent US20110012910A1 [27] claims a method which is described for using a texture synthesis approach to produce digital images that simulate motion. The system operates by receiving a large-scale motion image that describes large-scale motion, as well as one or more exemplar images that describes small-scale motion. The system then applies a texture synthesis approach to duplicate the small-scale motion described in the exemplar image(s), as guided by the large-scale motion described in the large-scale motion image. This operation produces a synthesized motion image. The system then combines the synthesized motion image with the large-scale motion image to produce a combined motion image. The combined motion image presents the large-scale motion as modulated by the small-scale motion. The system can also take account for one or more application-specific constraints, such as incompressibility and boundary conditions.

3.7. Texture Synthesis and Image Repair Method Based on Wavelet Transformation

Patent CN101635047 [28] claims a texture synthesis and image repair method based on wavelet transformation. The method comprises the following steps: performing the wavelet transformation on an input damaged image, and decomposing the image into a low-frequency sub-image and three high-frequency sub-images; marking a repair region of the original image to form a binary mask image and sampling the mask image to match resolution of the mask image with a wavelet sub-image; analyzing structural information of the original image by a high-frequency coefficient of wavelet decomposition to determine a repair sequence of defect pixels, and filling and repair various sub-images by the texture synthesis method; and performing wavelet inversion on various wavelet sub-images to obtain the repaired image. The method helps repair the image in combination with structure and texture information of the image on the basis of the wavelet transformation, has excellent effects of repairing large-area damage images and greatly improves repair efficiency.

3.8. Texture Synthesis Method Based on Interval Distribution of Texture Blocks

Patent CN101620737 [29] claims a texture synthesis method based on interval distribution of texture blocks, belonging to the fields of computer algorithm, computer graphic technology, image processing technology and texture generating technology. The method comprises the following steps: (a) analyzing the sample texture to determine the size of a main body portion and an overlapping portion of the texture blocks; (b) dividing the sample texture according to the size to obtain a texture block aggregation M; (c) classifying the texture block according to phase, wherein each phase corresponds to one type; (d) obtaining four compatible adjoining aggregation of each texture block; (e) obtaining a proper texture block aggregation; (f) selecting any texture blocks to fill a target texture from the proper texture block aggregation, wherein blank blocks with or without texture blocks are distributed at intervals in transverse direction or longitudinal direction; (g) filling the left blank blocks; and (h) seaming the overlapping portion. The invention can be used for texture synthesis.

3.9. Method and Assembly for Video Encoding

Patent US7949053 [30] claims a method for video coding comprising a texture analysis, texture synthesis, corresponding computer program and a computer-readable recording medium. They said invention can be used, in particular for reducing a data rate during a video data transmission. An analysis of video scene texture by an encoder is performed in such a way that synthesized texture areas are determined. The video scene coding is carried out with the aid of data for said synthesized texture areas. Information on the texture of said areas, metadata used for describing the determined areas and the synthesized texture are generated. Coded data and metadata are evaluated by a decoder in such a way that the video scenes are reconstructed by synthetically generated textures by means of evaluation of metadata for determined areas.

3.10. Methods and Apparatus for Texture Compression Using Patch-based Sampling Texture Synthesis

Patent US20110091120 [31] claims methods and apparatus which are provided for texture compression using patch-based sampling texture synthesis. An apparatus includes an encoder for encoding texture for a picture by synthesizing the texture. The encoder performs texture synthesis using a patch-based sampling method, thus determining "displacement vectors" indicating positions of patches in an input sample texture which are to be synthesized. At the encoder, both the input sample texture and information representing the "displacement vectors" are coded. At the decoder, the new patches are generated by directly using the "displacement vectors".

4. CURRENT & FUTURE DEVELOPMENTS

As can be seen from the articles and patents reviewed in section 3, the area of texture synthesis has already been well studied by many researchers. There are inventions that achieve parallelism and get more controllable. These methods can be computed in real-time on a GPU. Meanwhile, there are inventions that attempt to acquire some inner information of the texture example to improve the synthesis quality. It is important for researchers and developers to realize that visual features of the textures can play a very significant role in enhancing the quality of the synthesis results.

Most existing texture synthesis algorithms take a single exemplar as input and generate an output texture with similar visual appearance. Although the output texture can be made of arbitrary size and duration, those techniques can at best replicate the characteristics of the input texture. In the near future, we think that techniques which can take multiple textures with probably different characteristics, and synthesize new textures with combined visual appearance of all the inputs will be developed. Also, methodologies developed for this field can be used in many fields such as computer animation, virtual reality, data compression, Non-Photorealistic Rendering and so on.

ACKNOWLEDGEMENT

This work is supported by National Natural Science Foundation of China (No.60872120, 60902078, 61172104), by Beijing Natural Science Foundation (Content-Aware Image Synthesis and Its Applications, No.4112061), by French System@tic Paris-Region (CSDL Project) and ANR-NSFC(No.60911130368).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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