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Transform domain texture synthesis

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Abstract

In this paper, we propose a fast DWT-based multi-resolution texture synthesis algorithm in which coefficient blocks of the spatio-frequency components of the input texture are efficiently stitched together to form the corresponding components of the synthesised output texture. We propose the use of an automatically generated threshold to determine the visually significant coefficients, which act as elements of a matching template used in the texture quilting process. We show that the use of a limited set of visually significant coefficients, regardless of their level of resolution, not only reduces the computational cost, but also results in more realistic texture synthesis. A transform domain texture blending strategy is used to remove the remaining artefacts across edges, improving the synthesised texture quality further. We use popular test textures to compare our results with that of the state-of-the-art techniques. Some application scenarios of the proposed algorithm are also discussed.

Keywords: Texture synthesis; Image quilting; Multi-resolution; Wavelet transforms

1. Introduction

In order to enhance the visual realism in virtual scenes, non-geometric finer details need to be added. Among the methods experimented by researchers, capturing the real word appearance by photographs and using them for creating the virtual scenes has been the most successful. Texturing surfaces has thus attracted much interest with an increasing number of animated movies produced in recent years. Texture synthesis is particularly useful in modelling repetitive patterns such as human and animal skin, stone, wood, marble, etc.

The problem of synthesising textures has been studied extensively and numerous approaches have already been proposed. So far the most common approach to texture synthesis has been to develop a statistical model which emulates the generative process of the texture that it is intending to mimic. Markov Random Field (MRF) is a widely used texture model [1–5], which assumes the underline stochastic process is both local and stationary. Another common approach is the physical simulation of the texture. In this method texture generation is done by directly simulating the physical generation process of certain textures such as corrosion, weathering, etc.

The inspiration for our work comes from the two patch-based algorithms proposed by Efros and

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Freeman [6] and Lin Ling and C Liu [7]. Both of these algorithms use patch-based sampling and in addition the second addresses the problem of constrained texture synthesis. These algorithms produce reasonably good-quality results with less computation cost compared to other algorithms.

In Efros and Freeman's algorithm the output texture is formed by selectively transferring randomly selected blocks of a predefined size from the input texture image. Given that the top left-hand corner block of the output image has been appropriately formed, a subset of blocks from which a good candidate for the block to its right (assuming a raster scanned order) is found as follows: All possible blocks of the same block size from the input image are matched to the first block (top left-hand corner) of the output image, under a certain overlap. Unfortunately this algorithm cannot be used for real time texture synthesis, as its efficiency is relatively low. The use of exhaustive searching in choosing the best match causes computational power to be wasted. Due to the use of a random picking technique in selecting the final block to be patched with the preceeding block, often the seam between the two adjacent blocks is quite visible. Even though a minimum error boundary cutting technique is used to smoothen off these sudden changes in texture, it involves computationally expensive methodologies such as dynamic programming and thus would not be suitable for real time applications.

Recently Kwatra [8] proposed another patch-based approach using a graph cut technique to find the optimal cutting path along the edges. Entire patch matching is carried out initially and sub-patch matching is done in refinement passes. In entire patch matching the patch is overlapped with different offsets and the best patch is selected using a probability function. Sub-patch matching involves overlapping error regions with patches of different offsets. As these two steps involve large overlaps high computational power is required in calculating the overlap error. Therefore, they have proposed a FFT-based acceleration to speed up the algorithm. It is stated that the use of FFT decreased the complexity of image matching from $O(n^2)$ to $O(n\log(n))$, where n is the number of pixels in the sample image. In a typical texture synthesis process n is a constant and is not very large as for video textures.

In order to resolve the problems discussed above, in our previous work we proposed a Discrete Wavelet Transform (DWT)-based multi-resolution image quilting algorithm [9] in which coefficient-blocks of the spatio-frequency components of the input texture are efficiently *stitched* together to form the corresponding components of the synthesised output texture. In this paper, we propose major improvements to this algorithm in terms of speed and the quality of synthesized texture. In particular, we adopt a modified version of the Embedded Zerotree Wavelet (EZW) coding algorithm of Shapiro [10], popularly used in progressive coding of images, in achieving progressive texture synthesis capabilities. Using theoretical and experimental analysis we show that the complexity of our algorithm is of order $O(n)$, where n is the number of pixels in the sample texture.

The proposed texture synthesis algorithm consists of the following features.

- A DWT framework which provides a compact multi-resolution representation of texture.
- A Zerotree [10]-based approach providing an ordered representation of perceptually significant coefficients.
- A multi-resolution construction capability of synthesized texture.
- The possibility of being used in bandwidth adaptive systems requiring dynamic quality/speed adjustments.
- Fast mapping in hardware with low processing power.

The above features specifically make it viable for the proposed texture synthesis algorithm to be used in association with the progressive 3D surface coding and transmission algorithms, such as MESHGRID [11], considered within the MPEG-4 AFX standardisation activities [12].

For clarity of presentation, the rest of the paper is divided into four further sections as follows. Section 2 introduces the reader to the basics of DWT-based analysis of a texture image and a summary of our previously proposed multi-resolution texture synthesis algorithm. Section 3 presents the proposed multi-resolution framework. Section 4 provides experimental results and a comprehensive analysis of the results. Finally Section 5 concludes, with an insight to possible improvements and future variations.

2. Multi-resolution texture synthesis and the previously proposed algorithm

A texture image contains large amounts of perceptual data. Therefore the number of bits