Novel Path Search Algorithm for Image Stitching and Advanced Texture Tiling

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ABSTRACT

We propose a fast and adjustable sub-optimal path search algorithm for finding minimum error boundaries between overlapping images. The algorithm may serve as an efficient alternative to traditional slow path search algorithms like the dynamical programming. We use the algorithm in combination with novel adaptive blending to stitch image regions. The technique is then exploited in a framework for sampling-based texture synthesis where the learning phase is clearly separated and the synthesis phase is very simple and fast. The approach exploits the potential of tile-based texturing and produces good and realistic results for a wide range of textures.

Keywords

Path Search, Image Stitching, Image Transfer, Adaptive Blending, Texture Tiling, Texture Synthesis.

1. INTRODUCTION

Physically correct virtual model visualization can not be accomplished without naturally looking color textures covering virtual or augmented reality scene objects. These textures can be either smooth or rough (also referred to as BTF, see e.g. [MMu03]). The rough textures do not obey the Lambert law and their reflectance is illumination- and view-angle-dependent. Both types of textures occurring in virtual scene models can be rendered either through digitalization of natural samples or by synthesis from appropriate mathematical models. Exact sample digitalization may become prohibitive due to considerable memory requirements, particularly in case of BTFs where each texture is represented by a possibly high number of illumination and view-angle-dependent images. Therefore several texture synthesis methods have been defined to reduce the memory complexity. The related methods may be divided primarily to either intelligent sampling or model-based-

Figure 1. The picture is made of rectangular tiles. Can you guess, what is the tiling grid size and how many different tiles have been used ? (see Fig.10)

analysis and synthesis. The model-based techniques (see, e.g., [Bes74], [Kas81], [BK98], [Hai91], [PJ00], [GH03], [HH00], [HH02]) describe texture data by means of multidimensional mathematical models and later use an extremely compact representation for seamless synthesis of arbitrarily sized texture images. Intelligent sampling approaches (see, e.g., [DB97], [EL99], [Efr01], [Hee95], [XGS00], [CS03], [KS03]) rely on sophisticated sampling from real texture measurements. Sampling based methods currently achieve better visual quality at a cost of less effective compression. Particularly the simpler intelligent-sampling methods have been receiving constant attention for their applicability in graphic hard-

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ware. DeBonet's method [DB97] constructs the texture in coarse-to-fine fashion, preserving conditional distribution of filter outputs over multiple scales, while another multi-scale method [Hee95] uses histograms of filter responses. The "image quilting" method [Efr01] by Efros et al. connects rectangular pieces of the texture sample together while minimizing the boundary cut error. Similarly the algorithm by Xu et al.[XGS00] uses regular tiling combined with a deterministic chaos transformation. Very good results can be achieved by employing Wang tiles [CS03] or the so-called graphcut textures [KS03]. All of these methods implement some sort of source texture sampling and the best of them often produce very realistic synthetic textures.

However, no texture synthesis method can be considered ideal for all potential applications. Either the performance, universality, visual quality of results or applicability in current hardware may become the prohibiting factor.

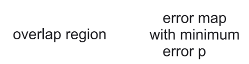
Our Motivation

Many of the current sampling methods involve image operations that may result in visible seams, typically when combining incompatible pieces of texture. A good way to improve the visual quality in such cases is to find (possibly irregular) boundaries between the image pieces to minimize the visual error. In the following we propose a sub-optimal yet highly effective alternative to traditional slow path-search algorithms. Taking use of the algorithm we show a method of developing the texture by visually unrecognizable image transfers (to be referred to as patching). We also show how to utilize this technique in a simple way to obtain groups of mutually connectable tiles representing the given texture. However, the main part of the paper concentrates on the path search and seamless boundary creation problem as we believe the solution presented here is generally usable in many different contexts and applications.

The paper is structured as follows: Section 2 discusses in detail how a virtually invisible transition between two texture image regions can be created. Section 2.1 shows a novel sub-optimal algorithm for path search that can be used instead of slow exponential algorithms like the dynamical programming. Section 2.2 shows how to improve the visual transition quality in cases when minimum error path does not suffice to prevent discontinuities. Section 2.3 extends the stitching technique to enable seamless transfer of whole image regions (patching). In Section 3 we show a trivial yet well-performing way of seamless tile creation. Assuming one tile has been created, we show in Section 3.2 how new, visually different derivatives can be created based on it while all of the tiles remain mutually connectable. Such tile sets can then be used to synthesize texture images of significantly higher quality than it is possible with simple tiling approaches, as shown in the Experiments Section 4. Section 5 summarizes the advantages and discusses the drawbacks and perspectives of the proposed methods.

2. IMAGE STITCHING

Consider *image stitching* a process of creating natural transitions between two image regions. This task is simpler for naturally self-similar (e.g. homogenous) textured images. The transition is to be made as unnoticeable and indistinguishable from the neighboring image areas as possible. We define the technique based on the minimum error boundary cut idea, as used in the "image quilting" algorithm [Efr01]. Let us assume that each stitch between two equally sized overlapped image regions R_1 and R_2 is oriented. A right-oriented stitch image will consist mostly of pixels from R_1 along its left side and mostly of pixels from R_2 along its right side. Creating such stitch can be imagined as attaching a cropped part of R_1 (source) to R_2 (target) as demonstrated in Figure 2. The following sections show in detail how to crop and how to reduce unwanted visual errors for cases when cropping itself is not sufficient.



Adaptive Boundary Blending

The minimum path based stitching often produces good natural appearance of image transition areas. However, if no good path exists in the error map, visible artifacts can not be avoided (as demonstrated in Figure 5–simple stitch).

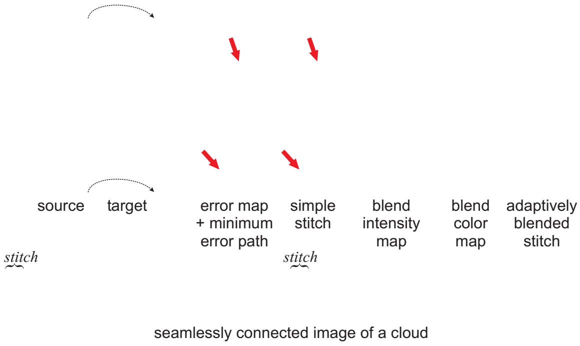


Figure 5. Adaptive blending to improve visual consistency of stitched image areas.

Therefore we have defined the *adaptive boundary blending* as an attempt to reduce the visibility of such unwanted and striking high-error artifacts, should they emerge during the stitching process. The idea is to interpolate between overlapped source region R_1 and target R_2 with a locally adjusted intensity while utilizing the *minimum error path* both as a boundary and as a coloring guideline. Our experiments show that to prevent unnaturally smoothed appearance it is better to keep the affected area minimal, just enough to mask the high error artifacts. In the following we consider a right-oriented stitch again. This is of importance now, because the blending process we adopt is targeted to one side (left in this case) of the path only what helps to better preserve the original image appearance.

Let us denote S the adaptively blended stitch region of $w{\times}h$ pixels to be created from R_1 overlapping R_2. We assume the minimum error path $Path^{\mathbf{c}}$ and error map E are known (see the previous Section). The *blending range* (maximum distance from the path where pixels get affected) is to be set as parameter ρ. The ρ value should be specified with respect to the properties of the processed source image. Higher image resolution should be reflected on higher ρ. However, with ρ being too high the blending effect can become visually too apparent. On the contrary, too small ρ may not be sufficient to suppress the worst visual stitching errors, should they appear. The stitch is created row-wise, i.e., for each $j = 1, \ldots, h$:

$$S[i,j] = \begin{cases} R_2[i,j] & \text{for } c_j < i \le w \\ R_1[i,j] * \alpha + R_2[m,n] * (1-\alpha) & \text{for } 1 < i \le c_j \end{cases}$$

where

$$(m, n) = \mathrm{ar}$$

5. CONCLUSION

We have presented a novel fast path search algorithm and adaptive blending technique that are suitable for seamless image transfer, in particular in the context of texture synthesis. Using these tools we have demonstrated a relatively simple technique that enables synthesis of naturally looking textures by means of advanced image tiling. We show how a set of mutually connectable yet differently looking rectangular tiles can be obtained for a broad range of source texture measurements. We show that even very irregular textures can by represented well using such tile sets. The main advantage of the presented technique is the clear separation of the off-line texture analysis, while the synthesis is reduced to trivial combination of precomputed tiles. The visual quality of output is close or comparable to the best of current techniques as shown in Figures 8 and 11.

The tiling technique is scalable. The trade-off between the visual quality and computational complexity can be controlled by changing the number of tiles in the tile set. For each texture some minimum number of tiles is usually necessary to ensure sufficient quality of results. Regular (possibly rectangular) textures without much detail can be represented by fewer tiles than highly irregular stochastic textures. Most of the algorithms presented here are extendable or modifiable. We have found the technique to be extendable for BTF modeling (bidirectional texture fields, see, e.g. [MMu03], [MMe03]) to enable particularly accurate display of natural surfaces with respect to view- and illumination- angles.

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