Generalized Roller

Michal Haindl & Martin Hatka
Institute of Information Theory and Automation
Academy of Sciences of the Czech Republic
CZ18208, Prague, Czech Republic
{haindl,hatka}@utia.cz

ABSTRACT

This paper describes a generalization of our previously published simple roller method for seamless enlargement of colour textures such as natural bidirectional texture functions (BTF) that realistically represent appearance of given material surfaces. The generalized roller allows automatic detection of major texture periodicity directions which do not need to be aligned with coordinate axes. The roller texture synthesis method is based on the overlapping tiling and subsequent minimum error boundary cut. One or several optimal double toroidal BTF patches are seamlessly repeated during the synthesis step. While the method allows only moderate texture compression it is extremely fast due to complete separation of the analytical step of the algorithm from the texture synthesis part. The method is universal and easily implementable in a graphical hardware for purpose of real-time rendering of any type of static or dynamic textures.

Keywords
Texture Enlargement, Texture Sampling.

1 INTRODUCTION

A realistic physically correct visualization of virtual objects with real material surfaces require to map 3D shapes with genuine nature-like colour textures. However, the appearance of real materials dramatically changes with illumination and viewing variations. Thus the only reliable way for a material visual properties representation is to capture its reflectance in as wide range of light and camera position combinations as possible. This is the principle of the recent most advanced texture representation the Bidirectional Texture Function (BTF) [DvGNK99, HF07]. The BTF textures which have rugged surfaces do not obey the Lambert law and their reflectance is illumination and view angle dependent. The purpose of a synthetic BTF texture is to reproduce and enlarge a given real digitized texture image so that ideally both natural and synthetic texture will be indiscernible under any illumination or viewing condition. BTF types of textures which occur in virtual scenes models can be either digitized natural textures or textures synthesized from an appropriate mathematical model.
However modelling of a natural texture is a very challenging and difficult task, due to unlimited variety of possible surfaces, illumination and viewing conditions simultaneously with the strong discriminative functionality of the human visual system.

The related BTF texture modelling approaches may be divided primarily into intelligent sampling and model-based-analysis and synthesis [HF07], but no ideal method for texture modelling exists. Each of the existing approaches or texture models has its advantages and simultaneously limitations and thus the optimal texture modelling method always depends on the application and material to be modeled.

Model-based texture synthesis [Bes74, Kas81, Che85, BK98, BK99, Hai91, HH98, HH00, ZLW00, HH02, GH03a, HGS*04, HF07] requires non-standard multi-dimensional (3D for static colour textures and even 7D for static BTFs) models. If such a texture space can be factorized then these data can be modeled using a set of less-dimensional random field models [HF07], but in any case such models are non trivial and they suffer with several unsolved problems which have to be circumvented. Among such possible models the Gaussian Markov random fields [HF03] are advantageous not only because they do not suffer with some problems of alternative options (see [Hai91, Hai00, HH00] for details) but they are also relatively easy to synthesize and still flexible enough to imitate a large set of natural and artificial textures. Unfortunately real data space can be decorrelated only approximately, hence this approach suffers with some loss of image information. Alternative full nD models allow unrestricted spatial-spectral correlation modelling, but its main drawback is large amount of parameters to be estimated and in the case of Markov models also the necessity to estimate all these parameters simultaneously. Model-based methods are also mostly too difficult to be implemented in modern graphical card processors.

Intelligent sampling approaches [DB97, EL99, EF01, HB95, XGS00, LLX*01, LYS01, DC02, TZL*02] rely on sophisticated sampling from real texture measurements. Given a randomly selected starting block of texture in the image, they propagate out from it selecting new texture blocks. For each new block in the image, all neighboring blocks that have already been generated are checked and the example image (or images) is searched for similar textures. The k best such matches are found and then randomly chosen the corresponding new texture patch from among them. The methods [EF01, EL99, WL01] all vary in how the blocks are represented, how similarity is determined, and how the search is performed.

Intelligent sampling approaches, such as the presented method, are based on some sort of original small texture sampling and the best of them produce very realistic synthetic textures, usually better than model-based methods. However these methods require to store original texture sample, often produce visible seams, they are mostly computationally demanding, they cannot generate textures unseen by the algorithm, and they cannot approach the large compression ratio of model-based methods. This paper describes a generalization of our previously published simple roller method [HH05] for seamless enlargement of colour textures. The generalized roller allows automatic detection of major texture periodicity directions which do not need to be aligned any more with the coordinate axes.

The rest of the paper is organized as follows. The following section describes a simple sampling approach based on the repetition of a double toroidal tile carved from the original texture measurement. The algorithm is summarized in the section 3. Results are reported in the section 4, followed by conclusions in the last section.

2 DOUBLE TOROIDAL TILE

BTF is typically measured in the form of several thousand images covering many combinations of illumination and viewing angles, however, such measurements have huge size what has prohibited their practical exploitation in any sensible application until recently. The BTF data space for a single material (e.g. wood Fig.7) represents giga bytes of data for recent BTF measuring setups [MMK03]. Even though any sampling based method cannot approach compression ratio of alternative probabilistic BTF methods, it is still important to select double toroidal tiles as small as possible to compress these huge original measurements. We assume mutually well registered data of the size $N \times M$ for fixed viewing angle and changing illumination angle hence the algorithm is repeated for every viewing angle but produces simultaneously identical tiles for all illumination angles.

Periodicity Detection

The methods starts with the detection of two major texture periodicity directions. We compute the Fourier amplitude spectrum (Fig.2) from the grey-scale version of the perpendicularly illuminated input multispectral texture component. Two largest Fourier coefficients with angular difference larger than 10 degrees specify bisectors of two sectors Fig.1-bottom. Using the maximum correlation approach in these two sectors we find magnitude and direction $\vec{u} = (u_1, u_2)$, $\vec{v} = (v_1, v_2)$ for each major texture periodicity. If there are several local maxima in a given sector we choose the smallest periodicity maximum. These two directional vectors simultaneously specify two edges of the rhomboid to which is the double toroidal tile inscribed. The minimal rhomboid to which the tile is inscribed is limited not only by the sample spatial frequency content but also by the size of BTF measurements and the number of toroidal tiles we are looking for (n).

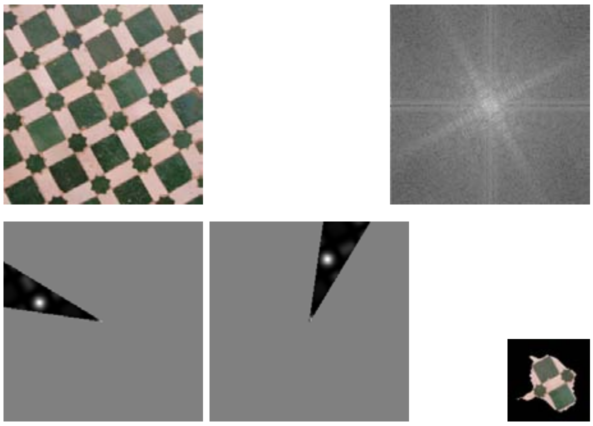

Figure 1: Original measured texture and its amplitude spectrum (upper row), detected spatial correlation sectors (bottom row) and the resulting toroidal tile.

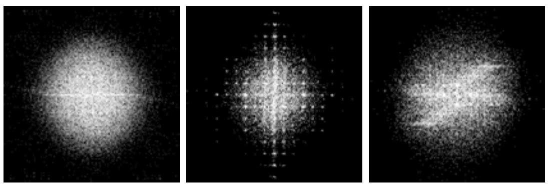

Figure 2: The amplitude Fourier spectra of the corduroy (Fig.8), proposte and wool textures, respectively.

Overlapping

The double toroidal tile (see Figs.1-bottom right,3-middle,) is limited by the selected minimal rhomboid to be inscribed in from the original texture measurement. The texture tile is assumed to be indexed on the regular two-dimensional toroidal lattice. The optimal lattice searched by the algorithm allows for seamless repetition in both $\vec{u}$ and $\vec{v}$ directions, respectively.

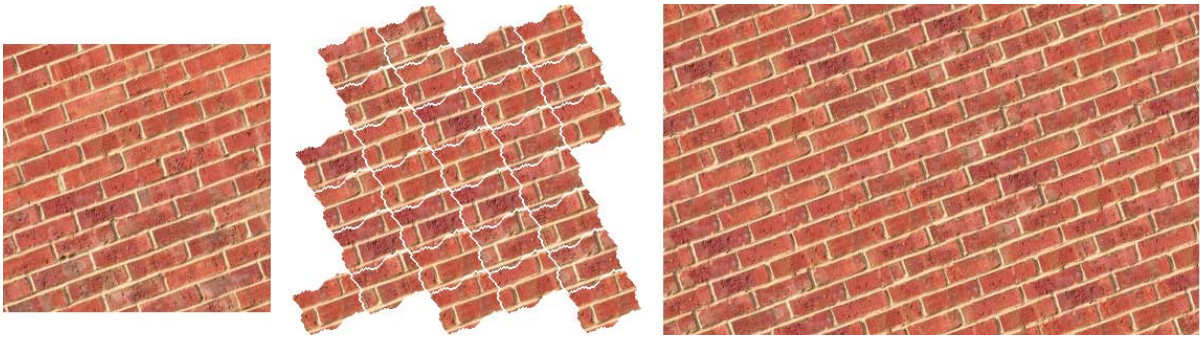

Figure 3: The roller principle - left input texture (left), combined toroidal tiles (middle), and the result (right), respectively.

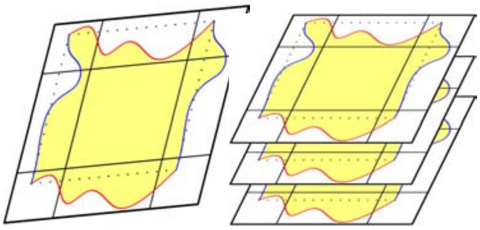

Figure 4: The optimal tile cuts in both directions (left) and the multiple tiles cut (right).

The multiindex r has two components $r = [r_1, r_2]$, the first component is row and the second one column index, respectively. Let us define the overlap error for a pixel r as follows:

$$\psi_r^u = \left(Y_r - Y_{r+[N,0]-\vec{u}}\right)^2 \quad \forall r \in I_u \ , \qquad (1)$$
$$\psi_r^v = \left(Y_r - Y_{r+[0,M]-\vec{v}}\right)^2 \quad \forall r \in I_v \ , \qquad (2)$$

where Y_r denotes a multispectral pixel indexed on the $N \times M$ underlying lattice and the index sets I_h, I_v are defined

$$I_u = (1,\ldots,u_2) \times (1,\ldots,M) \ ,$$
$$I_v = (1,\ldots,N) \times (1,\ldots,v_1) \ .$$

Optimal Cut

The optimal cuts for both the $\vec{u}$ and $\vec{v}$ edge is searched using the A^* algorithm. This suboptimal search method allows fast selection of both tile cuts. However for most applications the fast synthesis is prerequisite while the computation time for separately solved analytical part is of no significant importance. Both optimal cuts have to minimize the overall path error

$$\Psi_r^u = \psi_r^u + \min\left\{\Psi_{r-[1,1]}^u, \Psi_{r-[0,1]}^u, \Psi_{r+[1,-1]}^u\right\} \ ,$$
$$\Psi_r^v = \psi_r^v + \min\left\{\Psi_{r-[1,1]}^v, \Psi_{r-[1,0]}^v, \Psi_{r+[-1,1]}^v\right\} \ .$$

The combination of both optimal directional cuts creates the toroidal tile as is demonstrated on the Fig.4.

Multiple Tiles

Some textures with dominant irregular structures cannot be modeled by simple repetition of only one tile without clearly visible and visually disturbing regularly repeated effects. These textures are modeled by random changing of several tiles Figs.5,6 which have identical tile borders but different content. Similar tile rhomboids are searched using the correlation measure and such rhomboids are stacked and simultaneously optimally cut.

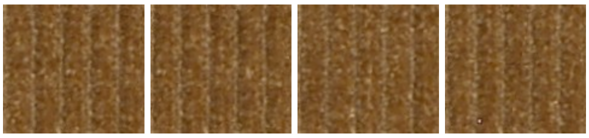

Figure 5: Multiple tiles for the BTF corduroy material.

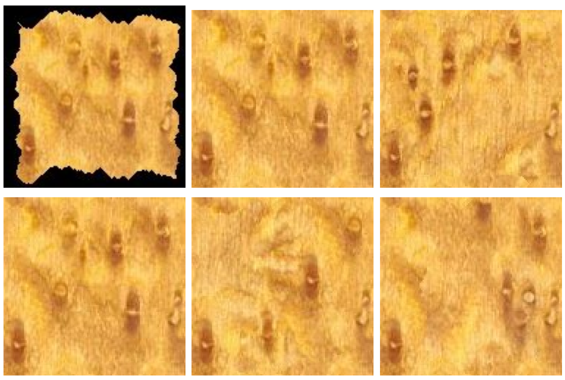

Figure 6: A tile and multiple rectangular tiles for the BTF wood material.

Synthesis

The synthesis of any required BTF texture size for a single tile case is simple repetition of the created double toroidal tile in both directions until the required texture is generated. There is no computation involved in this step hence it can be easily implemented in real time or inside the graphical card processing unit (GPU). In the

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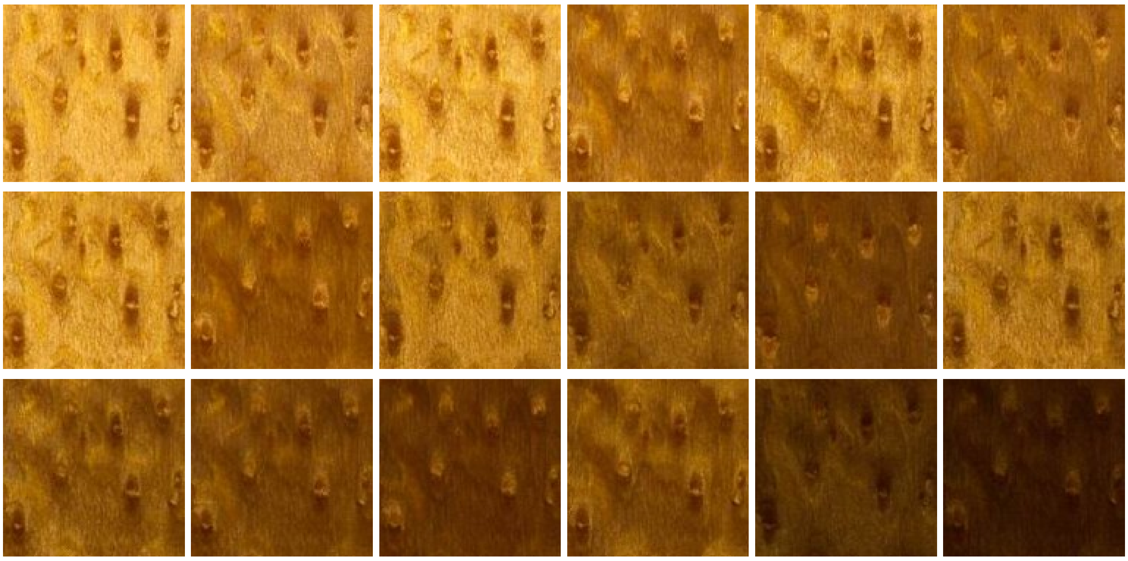

Figure 7: BTF wood rectangular tiles for different illumination angles.

case of several mutually interchangeable tiles we need a uniform random generator to decide which tile will follow. This additional computation is very simple and can be realized inside the GPU as well.

3 THE GENERALIZED ROLLER ALGORITHM

The completely automatic roller algorithm is as follows:

- Analysis
  1. Find the minimal inscribed rhomboid(s).
  2. Find the optimal vertex r^*.
  3. Search for optimal major periodicities directional cuts starting from r^* with final points in the corresponding rhomboid vertices.
  4. Create the double toroidal texture tile(s).
- Synthesis

The number of tiles is the only parameter specified by the user. The analytical part is completely separated from the synthesis. The most time consuming part of the analysis is the minimal tile specification together with its position in the input texture sample. In the worst case ($f_{r_1} = f_{r_2} = 2$) it is proportional to

$$T \propto MN^2 \frac{u_2}{2}(N - \frac{u_2}{2}) + NM^2 v_1 (M - \frac{u_2}{2}) \ .$$

The optimal cuts search time requirement is proportional to

$$T \propto v_1^2 \frac{u_2}{2} N - 2v_1^2 \frac{u_2}{2}^2 + M v_1 \frac{u_2}{2}^2$$

and interior replacement for multiple tiles needs:

$$T \propto (M - n_{col})(N - n_{row})(n_{col} \frac{u_2}{2} - n_{row} v_1) \ .$$

The optimal tile size evaluation time is in most graphical applications not important while the important synthesis step contains either no computations at all or only uniform number generation.

4 RESULTS

We have tested the algorithm not only on BTF textures (e.g. Figs.8,9,10) but also on several hundred colour and grayscale textures from the VisTex database [PGM*95], Noctua database, Brodatz textures [Bro66] and mainly from our extensive texture database, which currently contains over 1000 colour textures. Tested textures were either natural such as bark, wood, plants, water, etc., or man-made knitwear, upholstery, brick wall Fig.11, textiles, food products and many others.

Figure 8: Enlarged BTF corduroy material.

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Figure 9: Enlarged BTF wood material.

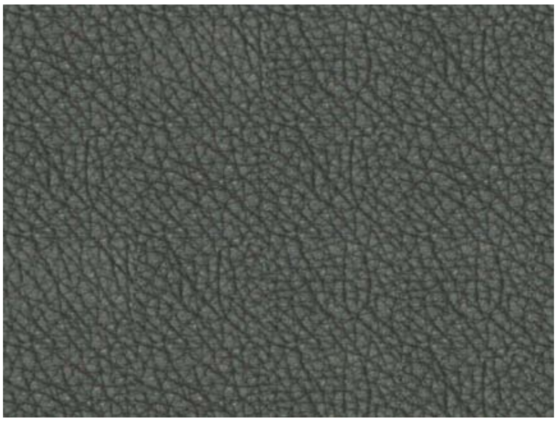

Figure 10: Enlarged BTF foil texture.

Several of these results (brick wall Fig.11, rattan Fig.12, leafs Fig.13, jeans cloth Fig.14, tiles Fig.16, text Fig.17, and plastic fence Fig.18) are demonstrated in the following images. Each image shows the input texture, one toroidal tile example, and the resulting synthetic texture, respectively. Such unusually extensive testing was possible due to simplicity and efficiency of the algorithm and it allowed us to get insight into the algorithm properties. BTF data we use are from the University of Bonn [MMK03]. We have tested the algorithm on BTF colour measurements such as upholstery, lacquered wood, knitwear or leather textures. Each BTF material sample comprised in the Bonn database is measured in 81 illumination and viewing angles, respectively and has resolution 800×800. Figs.8,9,10 demonstrate synthesized results for three different materials: fabric, wool and leather. Fig. 9 illustrates the lacquered wood smooth BTF synthesis.

Resulting textures are mostly surprisingly good for such a very simple algorithm. For example our results on the text texture (Fig.17) are indistinguishable (see [EF01]) from results on the same texture using much more complicated and slower image quilting algorithm [EF01].

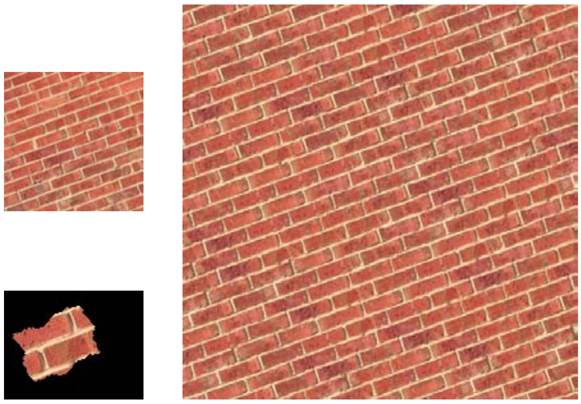

Figure 11: Enlarged brick texture.

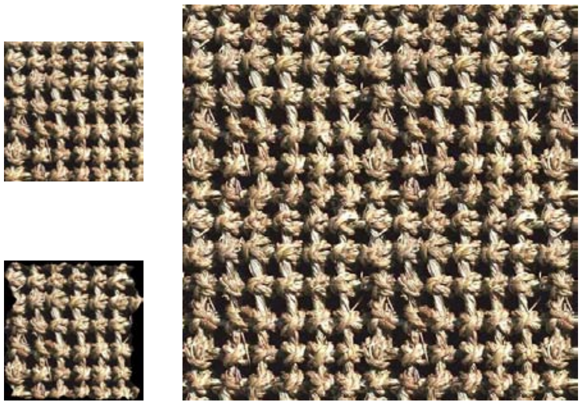

Figure 12: Enlarged rattan texture.

Figure 13: Enlarged leaves texture.

Obviously there is no optimal texture modelling method and also the presented method fails on some textures as can be seen on the following metal sheet example (Fig.19). But, this texture can be successfully modeled using the alternative probabilistic Markovian model [HH00]. The method also fails on textures with distinctive perspective distortion. However on most of our failure examples also most alternative intelligent sampling methods tested failed (e.g., [EF01] failed on the same metal sheet example on Fig.19 as well).

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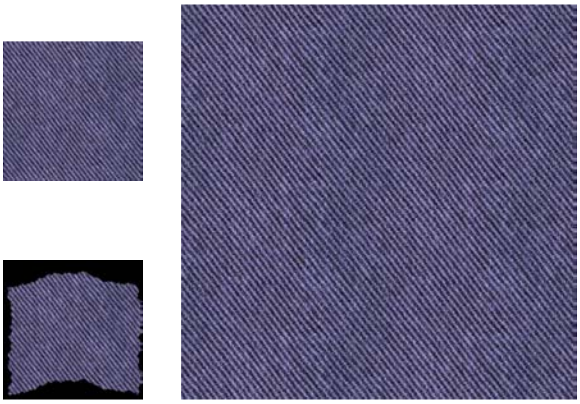

Figure 14: Enlarged jeans fabric texture.

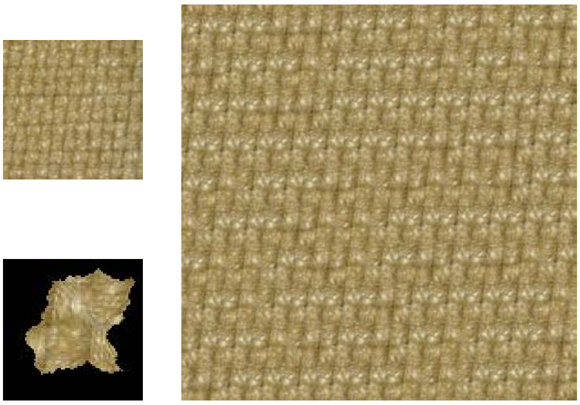

Figure 15: Enlarged woven matting texture.

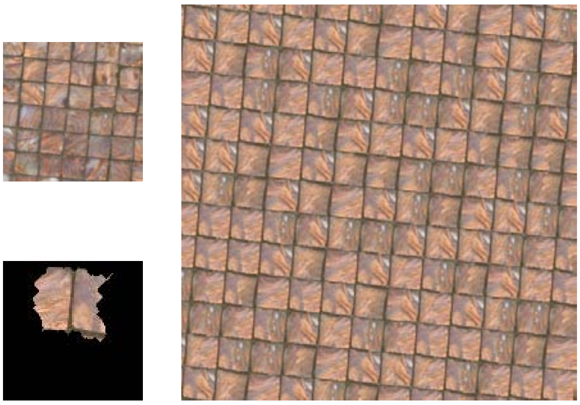

Figure 16: Enlarged shiny square tile texture.

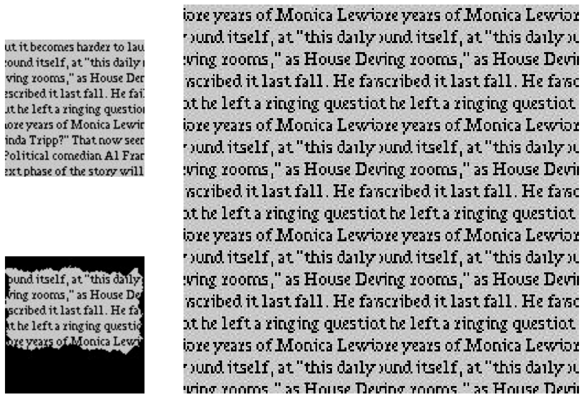

Figure 17: Enlarged newspaper texture.

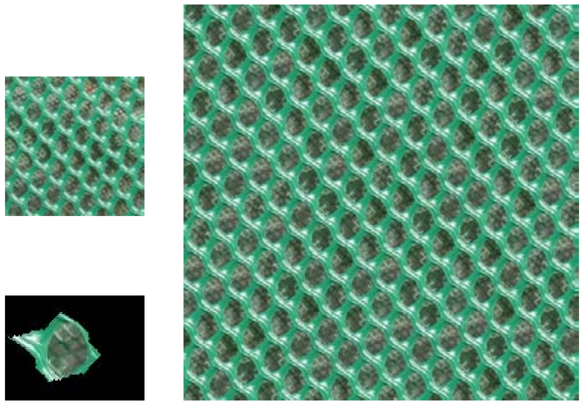

Figure 18: Enlarged plastic fence netting texture.

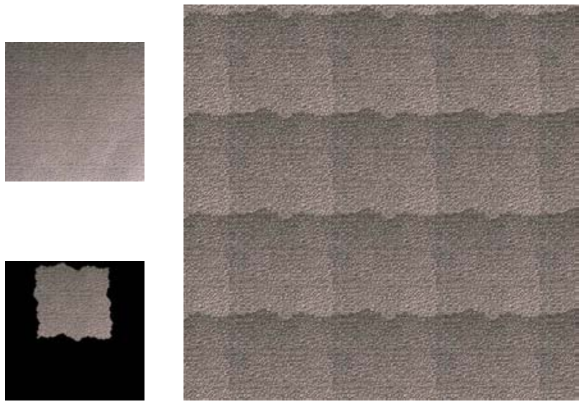

Figure 19: Metal sheet texture enlargement failure.

5 CONCLUSIONS

The test results of our algorithm on available BTF data are visually indiscernible for all our BTF data and also for most of tested colour textures. The test results of our algorithm on our extensive natural texture collection are encouraging. The presented method is extremely fast, fully automatic, very simple and easily implementable even in the graphical processing unit. The method offers only moderate compression ratio ($\approx 1:4$) for transmission or storing texture information while it has negligible computation complexity. Another drawback of the method is that it does not allow a BTF data space restoration or modelling of unseen (unmeasured) BTF space data unlike some probabilistic BTF models.

The roller method can be used for easy and fast seamless synthesis of any required texture size for many natural or man made BTF textures and their use in complex virtual reality scenes (Fig.20). The method's extension for alternative texture types or some other spatial data such as the reflectance models parametric spaces is straightforward.

6 ACKNOWLEDGEMENTS

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Figure 20: Chair retreat with several synthesized textures (left), detail (middle), and detail with tiled textures (right), respectively.

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