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Near-Regular BTF Texture Model

Michal Haindl Martin Hatka

Institute of Information Theory and Automation
of the ASCR, 182 08 Prague, Czech Republic
Email:{haindl,hatka}@utia.cz

***Abstract*—In this paper we present a method for seamless enlargement and editing of intricate near-regular type of bidirectional texture function (BTF) which contains simultaneously both regular periodic and stochastic components. Such BTF textures cannot be convincingly synthesised using neither simple tiling nor using purely stochastic models. However these textures are ubiquitous in many man-made environments and also in some natural scenes. Thus they are required for their realistic appearance visualisation. The principle of the presented BTF-NR synthesis and editing method is to automatically separate periodic and random components from one or more input textures. Each of these components is subsequently independently modelled using its corresponding optimal method. The regular texture part is modelled using our roller method, while the random part is synthesised from its estimated exceptionally efficient Markov random field based representation. Both independently enlarged texture components from the original measured textures representing one (enlargement) or several (editing) materials are combined in the resulting synthetic near-regular texture.**

***Keywords*-near-regular texture; texture editing; Markov random field; bidirectional texture function;**

I. Introduction

Realistic visual appearance of real or artificial surface materials require complex models capable to model material dependence on variable illumination and viewing conditions. The appearance of such materials significantly changes with illumination and viewing variations, any reliable representation of material visual properties requires capturing of its reflectance in as wide range of light and camera position combinations as possible. This is a principle of the recent most advanced texture representation, the Bidirectional Texture Function (BTF) [1].

The ultimate purpose of texture modelling is to find a descriptive representation capable to completely characterise visual properties of a surface material under all required observation conditions for its subsequent usage in various image analysis or synthesis applications. Texture synthesis aims to reproduce and enlarge a given measured texture image so that ideally both natural and synthetic texture will be visually indiscernible. BTF function is represented by thousands of measurements (images) per material sample [1], thus its modelling prerequisite is furthermore also significant compression capability [2] otherwise these huge BTF data spaces cannot be applied in practice using available computing hardware. Finally, the modelling method should enable also a simple intuitive BTF texture editing [3] so a scene designer could modify objects surface appearance by controlled texture modifications in such a way that the edited texture visual appearance is physically plausible and predictably corresponds to the anticipated projection.

We define near-regular textures (NR) as textures that contain global, possibly imperfect, regular structures as well as irregular stochastic structures simultaneously. Near regular textures are difficult to synthesise, however, these textures are ubiquitous in man-made environments such as buildings, wallpapers, floors, tiles, fabric but even some fully natural textures such as honeycomb, sand dunes or waves belong to this texture category. These textures can be modelled either in oversimplified smooth or physically correct rough (also referred as the bidirectional texture function) representation. The related texture modelling approaches may be divided primarily into sampling and model-based synthesis [4], but no ideal texture modelling method exists. Each of the existing approaches or texture models has its advantages and limitations simultaneously and it is applicable for a restricted subset of possible textures only.

Model-based methods [2], [4], [5] are also often too difficult to be implemented in contemporary graphical card processors. Sampling approaches [6]–[17] rely on sophisticated sampling from real texture measurements, they require to store original texture sample, thus they cannot come near the large compression ratio of the model-based methods. Neither model-based or simple sampling algorithms alone can satisfactorily solve the difficult problem of near-regular texture modelling.

The presented generalisation (BTF-NR) of our NR method [18] allows to model and edit BTF NR textures and to combine a non-BTF regular texture with a BTF measurement using a pseudo-BTF approximation. The BTF-NR method combines advantages of both basic texture modelling approaches by factoring a texture into factors that benefit best from each of two basic different modelling concepts. The principle of the method is to separate a set of BTF and or non-BTF texture measurements from one or several materials into regular and stochastic parts, to enlarge these

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parts separately and subsequently to combine these partial results (texture enlargements) or results from several different textures (texture editing) into the required resulting BTF texture.

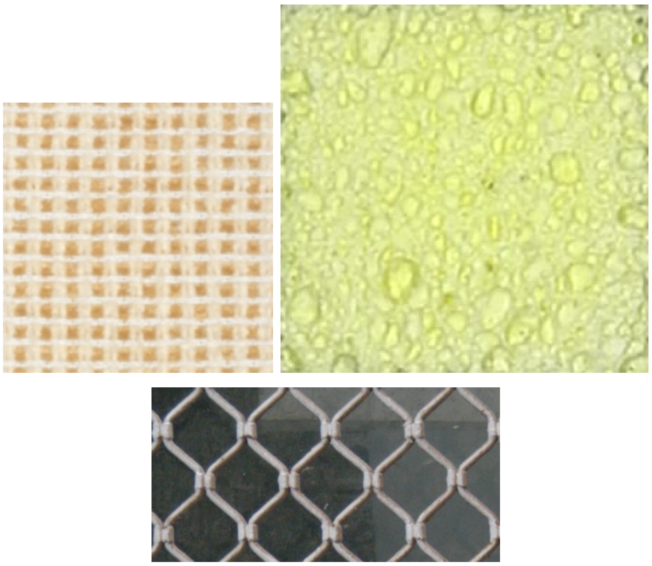

Figure 1. BTF proposte and sponge measurements and the iron bar.

II. Periodic Texture Detection

The prerequisite for our method is that the near-regular input BTF/smooth textures have distinct amplitude spectrum parts for both periodic and random components. Otherwise the BTF-NR method, outlined further, would not be able to separate both texture parts. Periodic and non-periodic texture part are detected in the most informative (PCA transformed) monospectral texture factor.

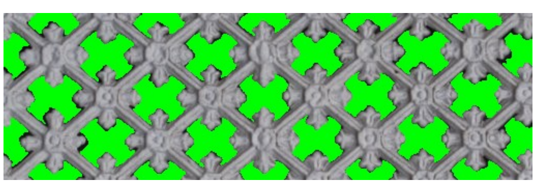

Figure 2. Detected grille.

Near-regular measured textures can have arbitrary periodicity directions, not necessarily simple axis aligned periodicity. The periodicity in two directions is detected from the spatial correlation field restricted with the help of Fourier amplitude spectrum [18]. The BTF-NR method finds two largest Fourier amplitude spectrum coefficients provided that they do not represent parallel directions. Detected periodicity and directions specify a rhomboid which contains the largest periodic part from the input texture. The texture cutout is filtered by the Fourier amplitude spectrum filter (see [18] for details) which removes coefficients smaller than a specified percentage of the largest amplitude spectrum coefficient and which is simultaneously neither local maximum nor a contextual neighbour of such a local maximum. The filtered and binarized tile (Fig.2) determines both the periodic as well as the stochastic texture part.

III. Periodic Factor Enlargement

The regular part of the texture is enlarged using a simplification of our fully automatic [9], [19] roller method. The method is based on the overlapping tiling and subsequent minimum error boundary cut to find the specified number of optimal (relative to the sample spatial frequency content) double toroidal texture tiles. All tiles share identical border but differ in their interior. Seamless enlargement is their random alternating in both directions until the required texture size is generated.

A. Shape Estimation

Regular textures often need to be estimated from a single non-BTF image because for different editing applications full BTF space measurements are not available or even impossible to measure for large not portable structures (e.g. iron bar on Fig.1). Such periodic texture is detected using the section II approach from a single image and its 3D structure shape recovery is estimated using the shape from shading approach [20] where we assume the Lambertian object surface (i.e. only diffuse reflectance), no interreflections and non-integrable surface slope estimates are projected onto the nearest integrable surface slopes. The enlarged periodic texture factor is subsequently pseudo-BTF approximated using the normal mapping [21] illumination modification.

IV. Random Factor Enlargement

The random factor of a NR-BTF texture is either synthesised from the original input texture from where the detected periodic component was removed as indicated in section II or learned from the whole BTF measurement for a non-NR texture input such as the background BTF texture on Fig.3. The random part of the texture is synthesised using an adaptive probabilistic spatial model [2], which is an exceptionally efficient type from the Markovian family (MRF) of models. Single steps of this method (i.e. BTF space intrinsic dimensionality estimation, BTF space segmentation, range map estimation, BTF subspace MRF model estimation, range map modelling, subspace MRF model synthesis and interpolation of unmeasured BTF space angles) are specified in [2]. The model allows extreme compression (few tens of parameters to be stored only) and can be speedily evaluated directly in a procedural form to seamlessly fill an infinite texture space.

The resulting near-regular texture is simple combination of both regular and stochastic synthesised factors originated from one (enlargement) or several (editing) BTF measurement spaces.

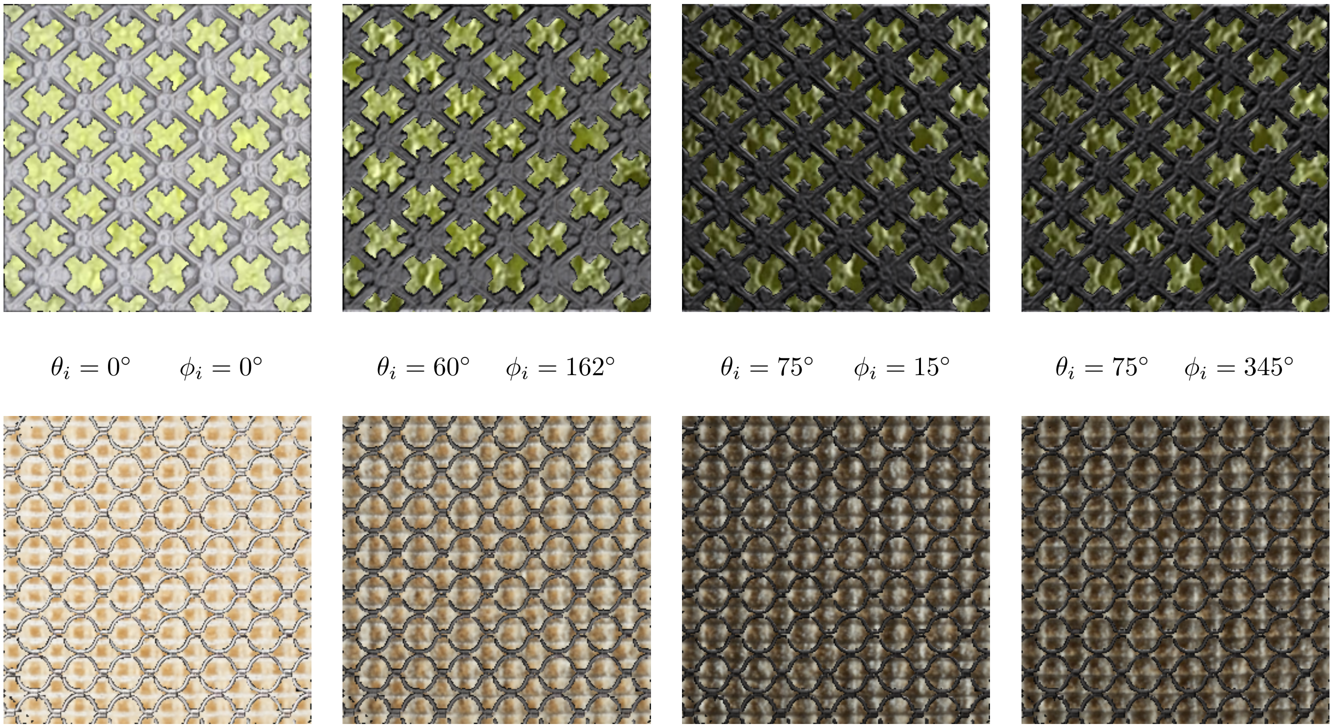

Figure 3. BTF sponge textures with grille (upper row) and proposte with iron bars for various elevation (θ_i) and azimuthal (ϕ_i) illumination angles.

V. Results

We have tested the presented BTF-NR model on natural colour textures from our texture database (http://mosaic.utia.cas.cz), which currently contains over 1000 colour textures and on BTF measurements either from the University of Bonn [22] or from the Yale University [23]. Tested textures were either natural, such as the sponge texture on Fig.1-right, or man-made textile on Fig.1-left. Each BTF material sample included in the University of Bonn database [1], [22] is measured in 81 illumination and viewing angles, respectively. A material sample measurements (Fig.1-left) from this database have resolution of 800×800 and size 1.2 GB. The Yale University measurements (Fig.1-right) have 90 viewing and 120 illumination angles. Fig.3 demonstrates BTF editing application, where both foreground iron textures were detected from one non-BTF image (Figs.1-bottom, 2) while both background textures were estimated from the BTF measurements. Fig.3 rows exhibit four such enlarged near-regular BTF textures for different illumination angles and fixed perpendicular view (elevation and azimuthal view angles are zero $\theta_v = \phi_v = 0°$).

Resulting synthetic near-regular BTF textures have physically convincing appearance and much better visual quality than alternative non-BTF textures using either model-based or sampling enlargement approaches. Both part of modelling were separately successfully tested on hundreds of colour or BTF textures with results reported elsewhere. Obviously there is no ideal texture modelling method and also the presented method fails on near-regular textures with similar (and thus faultlessly unseparable) amplitude spectrum parts of both periodic and random components.

BTF-NR is capable to reach huge BTF compression ration $\sim 1 : 1 \times 10^5$ relative to the original BTF measurements but $\approx 2\times$ lower than [2].

VI. Conclusions

The presented BTF near-regular texture synthesis or editing method allows huge texture compression because only tens of parameters per BTF-NR and few small range map and periodic texture tiles need to be stored or transmitted. The method is fully automatic and fast due to complete separation of the analytical step of the algorithm from the texture synthesis part. The periodic texture enlargement requires random tile repetition and shape based relighting while the random factor uses efficient random field model with analytical synthesis. Due to this stochastic modelling it completely eliminates visible repetitions (contrary to all usual tiling approaches) because there are never used two identical tiles in a scene. The method can be implemented in a graphical hardware for purpose of real-time rendering of any type of near-regular static textures. A drawback of the method is that it does not allow modelling of unseen (unmeasured) BTF space data unlike some fully parametric probabilistic BTF models.

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