Extended Bidirectional Texture Function Moving Average Model

Michal Havlíček*

6th year of PGS, email: `havlimi2@utia.cas.cz`
Department of Mathematics
Faculty of Nuclear Sciences and Physical Engineering, CTU in Prague

advisor: Michal Haindl, Pattern Recognition Department, Institute of Information Theory and Automation, ASCR

Abstract. The bidirectional texture function (BTF) is the recent most advanced representation of visual properties of material surface. It specifies its appearance due to varying spatial, illumination, and viewing conditions. Corresponding enormous BTF measurements require compact mathematical representation for visual fidelity preserving compression. We present a novel BTF model based on a set of underlying three dimensional moving average random field (3D MA RF) models. 3D MA assumes the texture considered as a product of a convolution of an uncorrelated three dimensional random field with a three dimensional filter which completely characterizes the texture. The BTF model combines several spatial factors, subsequently factorized into a set of 3D MA representations, and range map to produce the required BTF texture. This enables high BTF space compression ratio, unrestricted texture enlargement, and reconstruction of unmeasured parts of the BTF space. We also compare proposed model with its simpler two dimensional variant in terms of colour distribution fidelity.

Keywords: Bidirectional texture function, texture analysis, texture synthesis, data compression, virtual reality, moving average random field model

Abstrakt. Obousměrná funkce textur (BTF) je v současné době nejpokročilejší reprezentace vizuálních vlastností povrchu materiálu. Její vzhled se mění s měnícími se podmínkami osvětlení a s úhlem pohledu. Odpovídající naměřená data vyžadují kompaktní matematickou reprezentaci umožňující kompresi zachovávající vizuální věrnost. V tomto článku představujeme nový BTF model založený na sadě trojrozměrných modelů klouzavého průměru náhodného pole (3D MA RF). 3D MA předpokládá, že texturu lze považovat za produkt konvoluce s nekorelovaného trojrozměrného náhodného pole s trojrozměrným filtrem, který zcela charakterizuje texturu. BTF model kombinuje několik prostorově omezených faktorů reprezentovaných 3D MA a hloubkovou mapu k získání požadované BTF textury. Toto umožňuje kompresi BTF prostoru s vysokým kompresním poměrem, neomezené rozšíření textur a rekonstrukci nenaměřených částí BTF prostoru. Rovněž porovnáváme navržený model s jeho jednodušší dvourozměrnou variantou a to z hlediska věrnosti reprodukce barevného podání.

Klíčová slova: Obousměrná funkce textur, analýza textur, syntéza textur, komprese dat, virtuální realita, model pohyblivých průměrů náhodného pole

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[*] Pattern Recognition Department, Institute of Information Theory and Automation, ASCR.

1 Introduction

Realistic virtual reality scenes require objects covered with synthetic textures visually as close as possible to real surface materials appearance they emulate under any required viewing and lighting conditions. Recent most advanced visual representation of such surfaces is Bidirectional Texture Function (BTF) [2] which is a seven dimensional function describing surface appearance variations due to varying spatial position and illumination and viewing angles. Such a function is typically measured as thousands of images per material sample, each taken for a specific combination of the illumination and viewing condition. Textures can be either represented by digitized measured ones or synthetic ones represented by an appropriate mathematical model. Using digitized textures directly suffers among others with evidently extreme memory requirements.

Several so called intelligent sampling methods ([5] among others) were proposed to solve this problem. All of them are based on some sort of original small texture sampling. However, they still require to store thousands images for every combination of viewing and illumination angle of the original target texture sample and additionally they often produce images with undesirable visual artifacts. Moreover some of them are very computationally demanding.

Contrary to the sampling approaches, the synthetic textures generated from mathematical models are more flexible and extremely compressed, because only tens of parameters have to be stored instead of the original inconvenient visual measurements. They may be evaluated directly in a procedural form and can be used to fill virtually infinite texture space without visible discontinuities. On the other hand, mathematical models can only approximate original data, which might result in visual quality compromise. A BTF texture representation requires, in general, seven dimensional mathematical models, but it is possible to approximate the BTF with a set of much simpler three or two dimensional factorial models. Such a compromise obviously leads to some information loss.

We present a novel BTF model based on a set of underlying three dimensional moving average random field (3D MA RF) models. 3D MA model assumes the texture considered as a product of a convolution of an uncorrelated three dimensional random field with a three dimensional filter which completely characterizes the texture. As the proposed underlaying MA model suffers from inability to represent low frequencies present in natural textures we use multi scale extension of the model so that modelled texture is decomposed by means of Gaussian Laplacian (G-L) pyramid and each band limited component is modelled independently. The BTF model combines several spatial factors, subsequently factorized into a set of 3D MA representations, and range map to produce the required BTF texture.

BTF 3D MA model represents a novel method for efficient rough texture modelling which combines an estimated range map with synthetic smooth texture generated by the set of multiscale 3D MA models. The texture visual appearance during changes of viewing and illumination conditions are simulated using either the bump mapping [1] or displacement mapping [8] technique. The obvious advantage of this solution is the possibility to exploit direct support for both bump and displacement mapping techniques in the contemporary graphics hardware.

2 Three Dimensional Moving Average BTF Model

The BTF model combines the estimated and enlarged material range map with the synthetic smooth texture. The range map specifies overall roughness of the textured surface which significantly influences the BTF texture appearance. The BTF model range map estimate can benefit from tens of ideally mutually registered BTF measurements using the method called over determined photometric stereo [9] making such estimate much more accurate. The estimated range map is enlarged into required size using the roller [5], currently the most efficient texture synthesis algorithm.

Analyzed texture is decomposed into a multi resolution grid and each resolution data are independently modelled by their dedicated model. Each one generates a single spatial frequency band of the texture. Decomposition is performed using Laplacian pyramid and the intermediary Gaussian pyramid which is a sequence of images in which each one is a low pass down sampled version of its predecessor. The Laplacian pyramid contains band pass components and provides a good approximation to the Laplacian of the Gaussian kernel. It can be constructed by differencing single Gaussian pyramid layers. The hierarchy of different resolutions of an input image provides a transition between pixel level features and region or global features and hence such a representation simplify modelling a large variety of possible textures. Each band limited component is modeled independently.

A stochastic texture can be considered as a sample from a three dimensional RF defined on an infinite three dimensional lattice. Let us denote the input factor represented by the 3D MA RF model Y, then $Y_{(i,j,k)}$ is the intensity value of a pixel at (i,j) in k-th spectral plane of this factor. The model assumes that each factor is the stochastic texture and therefore the output of an underlying system which completely characterizes it in response to a 3D uncorrelated random input. This system can be represented by the impulse response of a linear 3D filter. The vectors of intensity values of the spectral planes of the most significant pixels together with their neighbours (defined by relative shifts $N(i,j) \in \mathcal{N}$, $i \in \{0,\dots,|\mathcal{N}|-1\}$, $j \in \{0;1\}$) are collected and averaged and the resultant 3D kernel is used as an estimate B of the impulse response of the underlying system. A synthetic factor $Y^{\dagger}$ can be generated by convolving an uncorrelated 3D RF E with this estimate:

$$Y^{\dagger}_{(i,j,k)} = \sum_{n=0}^{|\mathcal{N}|-1} \sum_{k'=0}^{c-1} B_{(n,k,k')} E_{(i+N(n,0),j+N(n,1),k')} \,, \qquad (1)$$

where c is the number of the spectral planes of the modelled texture.

2.1 Parameter Estimation

The parameters of B have to be estimated to fit the model equation (1) to certain image Y performing extended method used for two dimensional MA (2D MA) BTF model [4]. The procedure begins by selecting thresholds y_k, $k \in \{0,\dots,c-1\}$, usually chosen as some percentage $(\frac{0.5}{c})$ of the standard deviation of the intensities of the spectral plane k. The analysis itself starts from the top left corner of the image and proceeds to the bottom right corner identifying pixels at which the intensities in individual spectral planes cross the thresholds i.e. $(Y_{(i,j,k)} \geq y_k)$ and $((Y_{(i-1,j,k')} < y_{k'})$ or $(Y_{(i+1,j,k')} < y_{k'}))$ and $((Y_{(i,j-1,k')} < y_{k'})$ or $(Y_{(i,j+1,k')} < y_{k'}))$ holds. When such threshold crossing occurs the intensity values of all spectral planes of the support region defined by $\mathcal{N}$ around the crossing point are saved. The same procedure is followed at the next threshold crossing point and these intensity values are added to the previously saved. The summed up values are divided by the total number of contributions for the corresponding parameter estimates, i.e. averaged.

2.2 Synthesis

The underlying 3D MA model is able to generate synthetic images, i.e. stochastic smooth textures, $Y^{\dagger}$ directly from the parameters saved in B. The synthetic factor can be generated simply by convolving an uncorrelated 3D RF E with the estimate of B according to (1). All generated factors form new G-L pyramid. Fine resolution synthetic smooth texture is obtained by the collapse of the G-L pyramid i.e. an inverse procedure of that one creating the pyramid. Visual appearance of the resulting BTF texture is enhanced by including information from the estimated and enlarged range map using either the bump mapping or displacement mapping technique.

3 Results

We tested the model on BTF textures from the University of Bonn BTF database [7] which consists of several materials such as aluminium foil, corduroy, graved granite stone, leather, upholstery, wood. Each BTF material sample included in the database was measured in 81 illumination and 81 viewing angles and the resulting images have a resolution 800 × 800 pixels. Several achieved results can be observed in Fig.1 showing BTF texture of lacquered wood applied on nontrivial geometrical body. The presented scene was rendered with several different light conditions to demonstrate the effect and meaning of BTF texture use. We used used BTF texture plug in for Blender (a free and open source 3D animation suite) [6].

Comparison of the presented model with existing alternatives is hardly feasible as there is still a need for a reliable criterion for such validation. Many already developed approaches are limited to monospectral images that is clearly major disadvantage as colour is arguably the most significant visual feature. Currently, psychophysical experiments, i.e. quality assessments performed by humans, represent the only reliable option. Methods of this type require time demanding experiment setup design, strictly controlled laboratory conditions and representative set of human testing subjects. So that such experiments are extremely impractical, expensive, generally demanding. We simply render several common three dimensional textures modelled both by 3D MA model and its simpler two dimensional variant (2D MA). Several examples, which can be seen in Fig.2, clearly shows the information loss and therefore visual quality of the result caused by spectral decorrelation and thus definite advantage of the extended model.

Figure 1: **Several achieved results.** BTF texture of lacquered wood applied on non-trivial geometrical body rendered with several different light conditions. Comparison of 3D MA BTF model (odd rows) with 2D MA BTF model (even rows).

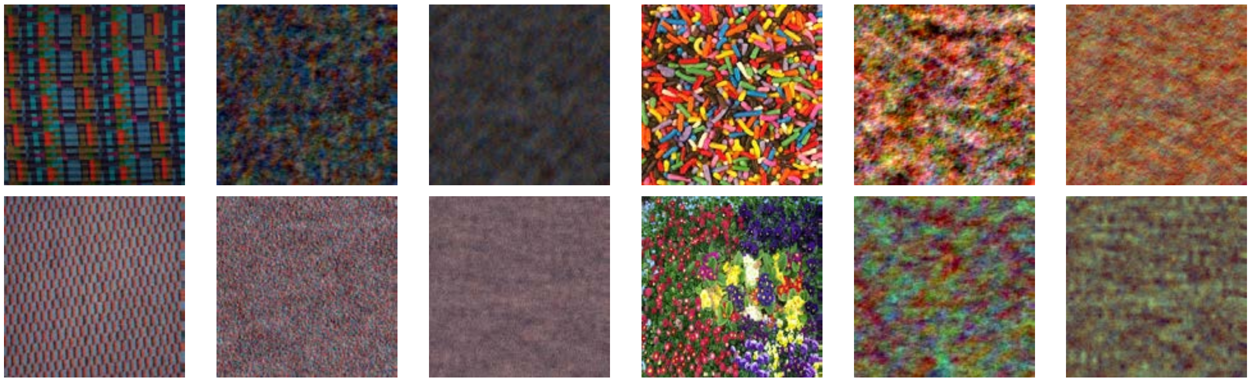

Figure 2: **Demonstration of the advantage of the extended model.** Comparison of original common three dimensional texture (the first image in each triplet) with 3D MA synthesis (the second image in each triplet) and with 2D MA synthesis (the third image in each triplet).

3.1 Future Work

Presented MA 3D model can be used as well as the core of compound texture model similarly to three dimensional causal autoregressive random field model in [3].

4 Conclusion

The presented BTF 3D MA model offers the possibility to compactly represent and theoretically unlimited enlarge BTF textures playing role as a simple alternative to the existing RF based BTF models. It is based on the extension of two dimensional BTF MA model.

The algorithm has very low computation complexity and does not require any in general time consuming numerical optimization such as the usually employed Markov chain Monte Carlo method or some of their deterministic approximations. Since this model is three dimensional and therefore outfitted for the treatment of multispectral data no spectral decorrelation is needed. Such decorrelation, necessary in case of two dimensional models, increases computing demands and is a cause of certain infomation loss leading to colour quality degradation of synthesized images. On the other hand, the inevitable spatial factorization increases overall time, memory, and computing demands.

BTF 3D MA model may be also used to reconstruct BTF space i.e. for the synthesis of missing BTF measurement. Due to its simplicity this method can be also potentially implemented taking advantage of new graphics cards to increase overall speed of both analysis and synthesis.

The results of the experiments on the BTF data are promising although they are only approximation of the original measurements. The presented method enables extremely fast and seamless enlargement of the BTF texture to arbitrary size and also very high BTF texture compression ratio which cannot be achieved by any alternative sampling BTF texture method. This is applicable for transmission, storing or modelling visual surface data.

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