Tutorial

Bidirectional Texture Functions Modelling

Applications

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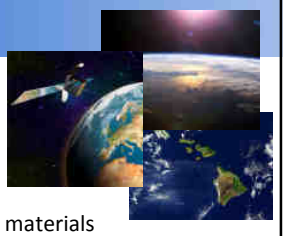
www.utia.cz

BTF Applications
Analysis



Visual Scene Interpretation

- Un/semi/supervised image segmentation
- V(A)R
- Study of human perception of materials
- CBIR - illumination and view invariant image retrieval
- Medical applications (dermatology, ophthalmology, ...)
- Remote sensing, security, etc.

BTF Applications
Synthesis

Accurate Visualization

- Virtual design (architecture, car industry, etc.)
- Visual safety applications
- Cultural heritage preservation
- Film & games industry
- 3D information systems (medicine, museums)

Illumination Invariants

Illumination, brightness & spectrum invariants

$\tilde{Y}_r = B\,Y_r$

2/3D CAR

[Vácha&Haindl09]

1. trace: $A_m,\ m = 1,\ldots,\eta K$
2. eigenvalues: $\nu_{m,j}$ of $A_m,\ m = 1,\ldots,\eta K,$ $j = 1,\ldots,C$
3. α_1: $1 + Z_r^T V_{zz}^{-1} Z_r$,
4. α_2: $\sqrt{\sum_r (Y_r - \hat{\gamma} Z_r)^T \lambda^{-1} (Y_r - \hat{\gamma} Z_r)}$
5. α_3: $\sqrt{\sum_r (Y_r - \mu)^T \lambda^{-1} (Y_r - \mu)}$, μ is the mean value of vector Y_r,
6. α_4: $\sqrt{\sum_r \hat{\sigma}_j^{-2} (Y_{r,j} - \hat{\gamma}_j Z_{r,j})^2}$,
7. α_5: $\sqrt{\sum_r \hat{\sigma}_j^{-2} (Y_{r,j})^2}$.

Illumination Invariants

2D GMRF

$$\beta_{1,j} = \ln\left(|\sigma_j^{2(I)}||\sigma_j^{2(I_1)}|^{-1}\right)$$

$$\beta_{2,j} = \ln\left(abs|V_{zz,j}^{(I)}|\ abs|V_{zz,j}^{(I_1)}|^{-1}\frac{|I_1|^\eta}{|I|^\eta}\right)$$

$$\beta_{3,j} = \ln\left(abs|V_{zz,j}||\sigma_j^2|^{-\eta}\,|I|^{-\eta}\right)$$

$$\beta_{4,j} = \ln\left(abs|V_{zz,j}||V_{yy,j}|^{-\eta}\right)$$

$$\beta_{5,j} = V_{yy,j}\,\sigma_j^{-2}\,|I|^{-1}$$

Illumination Invariants
Example CUReT recognition

Correct classification [%] using 4 random training images per material:

method	accuracy	vector size
MR8-LINC	67	600
Opponent Gabor features	68.7	252
$LBP_{8,1+8,3}$, grey	66.9	512
$LBP_{8,1+8,3}$, RGB	**70.9**	1536
$LBP^u_{16,2}$, RGB	68.7	729
2D CAR-KL, L_1	75.6	260
[cmyk]0.05,0.15,0,0 **2D CAR-KL 6+3**, L_1	**77.0**	**392**
3D CAR 6+3, L_1	72.4	344

Illumination Invariants

- ☑ Invariant to illumination brightness and spectrum.
- ☑ Robust to illumination direction.
- ☑ Fast implementation.
- ☑ Only one training image per material is required.

Unsupervised Segmentation

Problem Formulation:

- Unknown number of image classes.
- No training sets.
- Illumination spectrum, brightness, and position are unknown and variable.
- Realistic conditions.

Solution:

- Markovian texture representation.
- Illumination invariant parametric space.
- Gaussian mixture based parametric space segmentation.

Unsupervised Segmenters

MRF spatial models (3/2D CAR/GMRF)

$$Y_r = \sum_{s \in I_r} A_s Y_{r-s} + \epsilon_r$$

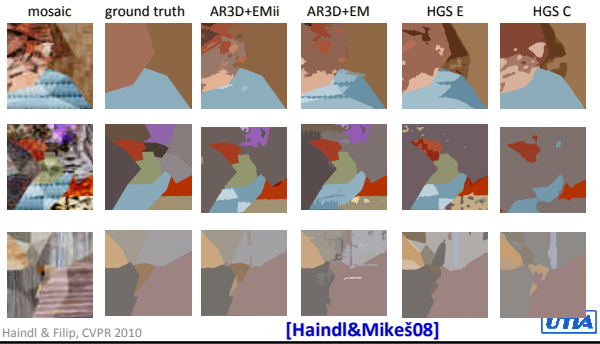
Parametric GM model

$$\begin{aligned} p(\Theta_r) &= \sum_{i=1}^{K} p_i \, p(\Theta_r \,|\, \nu_i, \Sigma_i) \ , \\ p(\Theta_r \,|\, \nu_i, \Sigma_i) &= \frac{|\Sigma_i|^{-\frac{1}{2}}}{(2\pi)^{\frac{d}{2}}} \, e^{-\frac{(\Theta_r - \nu_i)^T \Sigma_i^{-1} (\Theta_r - \nu_i)}{2}} \\ \Theta_r &= [\bar{\gamma}_r, a_r, b_r]^T \\ \bar{\gamma}_r^T &= \left[{}^t\psi, \, {}^b\psi, \, {}^r\psi, \, {}^l\psi\right]^T \\ {}^\alpha\psi &= [{}^\alpha\zeta_{1,1}, \ldots, {}^\alpha\zeta_{\eta,d}, \, tr\,{}^\alpha A_1, \ldots, tr\,{}^\alpha A_\eta] \end{aligned}$$

[Haindl et al.09a,b]

Prague Texture Segmentation Benchmark

http://mosaic.utia.cas.cz



[Haindl&Mikeš08]

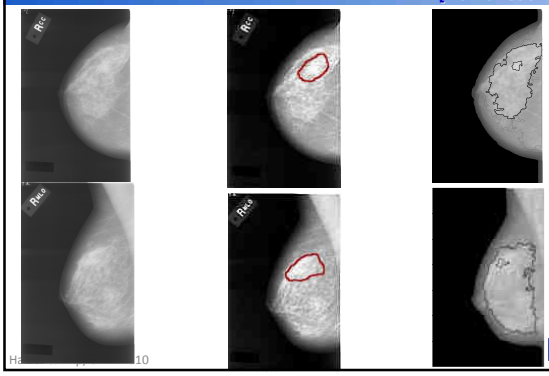
Prague Texture Segmentation Benchmark

http://mosaic.utia.cas.cz

	Benchmark – Colour (Illum. Inv.)			
	AR3D+EMii	AR3D+EM	HGS E	HGS C
↑ *CS*	40.70	34.14	9.55	9.17
↓ *OS*	53.02	53.33	19.30	12.80
↓ *US*	16.76	13.29	30.05	37.48
↓ *ME*	13.96	20.12	39.72	38.41
↓ *NE*	14.85	20.57	39.64	35.36
↓ *O*	35.17	31.53	56.44	68.87
↓ *C*	91.72	95.34	60.20	51.63
↑ *CA*	59.15	57.87	40.20	35.81
↑ *CO*	65.72	64.76	53.61	50.70
↑ *CC*	86.36	87.17	62.45	60.67
↓ *I.*	34.28	35.24	46.39	49.30
↓ *II.*	3.83	3.52	12.11	16.15
↑ *EA*	68.26	68.15	51.44	46.22
↑ *MS*	56.91	57.23	34.80	28.32
↓ *RM*	5.89	4.78	12.93	16.63
↑ *CI*	71.32	71.40	54.22	50.03
↓ *GCE*	14.34	16.99	25.36	21.31
↓ *LCE*	7.62	8.64	16.69	12.23
↓ *dM*	16.58	14.64	29.18	38.39
↓ *dD*	19.82	20.27	29.21	29.82
↓ *dVI*	15.80	16.75	13.98	12.61

Mammography ROI

[Haindl et al.07,08]



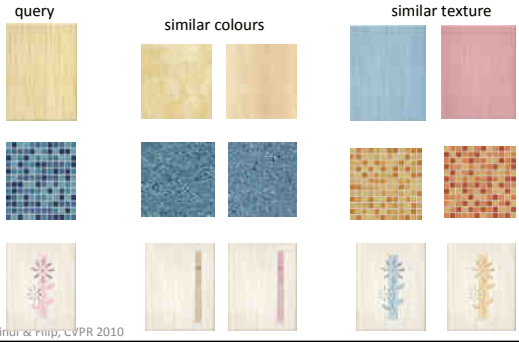
Unsupervised Segmentation

- ☑ Unsupervised & unknown number of classes.
- ☑ Invariant to illumination brightness and spectrum.
- ☑ Robust to illumination direction.
- ☑ Generalization to multi-segmenters systems.
- ☑ MRF based features.
- ☑ Fast implementation.
- ☑ Outperforms several alternative segmenters on extensive benchmark tests.

Content-Based Image Retrieval

tile retrieval http://cbir.utia.cas.cz/tiles/

query | similar colours | similar texture



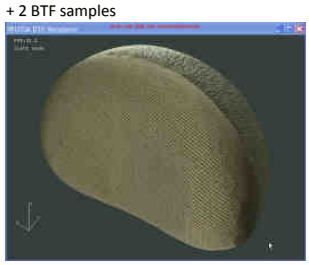
Virtual / Augmented Reality

- Virtual design (car / aircraft industry)
- Architecture
- 3D information systems
- Cultural heritage preservation

Virtual Representation of 3D Objects
Car Headrest Example

Original headrest

Measured geometry
(Konica-Minolta Vivid 9i)
+ 2 BTF samples



Architecture

- **Virtual Designing in Architecture**

Courtesy of RealReflect.org

Architecture

- **Virtual Designing in Architecture**

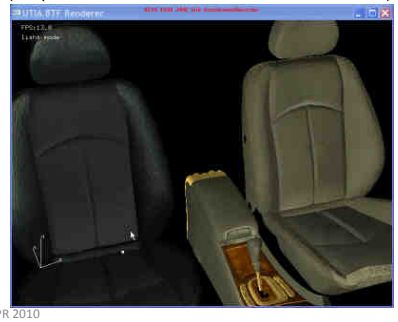
Car Industry
Virtual Interior Design

- **Virtual Designing in Automotive Industry**

Courtesy of RealReflect.org & University of Bonn

Car Industry
Virtual Interior Design

Interactive car interior design example
(sample selection and different illumination conditions)



Safety

- **Visual safety simulations**

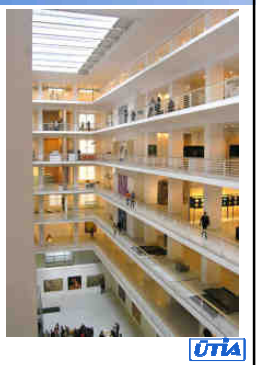
Courtesy of RealReflect.org &Univesity of Bonn

National Gallery - Department of Modern Art
3D Information System

- eight floors + two subterranean, two large halls
- among largest functionalist buildings in Europe
- built 1925 - 1928 (Oldřich Tyl & Josef Fuchs), 1974 destroyed by fire, 1995 reconstructed
- 19.-21. century art permanent exhibition on 13 500 m²

National Gallery - Department of Modern Art

- 3D interactive information system
- exhibition route planner (thematic & time constrained)
- distributed exhibition editor
- web gallery presentation
- traffic optimizer
- elderly and disabled visitors support
- safety simulator (evacuation rehearsal)



National Gallery - Department of Modern Art
Model Exhibition Route

Cultural Heritage Preservation

[Malzbender et al.01] neo-Sumerian tablet (2000 BC)

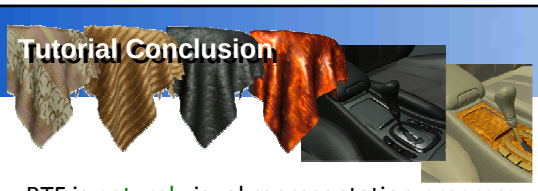
[Royal Library Sweden]

Codex Gigas
(1200 AD Podlažice, Bohemia, 1648 stolen by Swedish army from Prague)

Conclusions on BTF Applications

- ☒ Limited size of measurements (size, materials, resolution)
- ☒ Limited BTF space quantification
- ☒ Unmanageable size of BTF database
- ☒ Computationally demanding
- ☒ nD RF theory unsolved problems
- ☑ Physically correct material representation
- ☑ Descriptive representation → optimal analysis
- ☑ Tremendous application potential

Tutorial Conclusion



- BTF is natural visual representation progress binary ⇨ gray-scale ⇨ multi-spectral ⇨ BTF ⇨ …
- BTF offers ground-breaking image analysis & synthesis improvements
- BTF representation is a near future of computer vision & graphics & pattern recognition applications.

References

- Filip J., Haindl M.:*Bidirectional Texture Function Modeling: A State of the Art Survey*. IEEE TPAMI, 31(11), November 2009, pp. 1921-1940,
- Haindl, M., Filip J.: *Extreme Compression and Modeling of Bidirectional Texture Function*. IEEE TPAMI, 29(10), October 2007, pp.1859-1865.
- Filip J., Chantler M.J., Green P.R., Haindl M.:*A Psychophysically Validated Metric for Bidirectional Texture Data Reduction*. ACM Transactions on Graphics 27(5) (proceedings of SIGGRAPH Asia 2008), Article 138, 11 pp.
- Filip J., Chantler J. M., Haindl M.: *On Optimal Resampling of View and Illumination Dependent Textures*. ACM Transactions on Applied Perception, 6(3), August 2009, pp. 18

References

- Haindl M., Mikeš S., Vácha P.:*Illumination Invariant Unsupervised Segmenter*. ICIP 2009, pp. 4025–4028, IEEE Press
- Vácha P., Haindl, M.:*Illumination Invariant and Rotational Insensitive Textural Representation*. ICIP 2009, pp. 1333—1336, IEEE Press
- Haindl M., Mikeš S., Pudil P.:*Unsupervised Hierarchical Weighted Multi-Segmenter*. LNCS 5519, pp. 272–282, 2009, Springer-Verlag
- Haindl M., Mikeš S.:*Texture Segmentation Benchmark*. ICPR 2008, IEEE Press
- Haindl M., Mikeš S., Scarpa G.: *Unsupervised Detection of Mammogram Regions of Interest*. LNAI 4694, pp. 33–40, 2007, Springer-Verlag
- Malzbender T., Gelb D., Wolters H.:*Polynomial texture maps*. Eurographics 2001, pp. 519–528, ACM Press