Image-Based Rendering

Image-Based Rendering

Sing Bing Kang

Microsoft Research, USA
sbkang@microsoft.com

Yin Li

Microsoft Corporation, USA
yl@microsoft.com

Xin Tong

Microsoft Research Asia, China
xtong@microsoft.com

Heung-Yeung Shum

Microsoft Research Asia, China
hshum@microsoft.com

now
the essence of knowledge
Boston – Delft

Foundations and Trends® in Computer Graphics and Vision

Published, sold and distributed by:
now Publishers Inc.
PO Box 1024
Hanover, MA 02339
USA
Tel. +1-781-985-4510
www.nowpublishers.com
sales@nowpublishers.com

Outside North America:
now Publishers Inc.
PO Box 179
2600 AD Delft
The Netherlands
Tel. +31-6-51115274

The preferred citation for this publication is S. B. Kang, Y. Li, X. Tong and H.-Y. Shum, Image-Based Rendering, Foundations and Trends® in Computer Graphics and Vision, vol 2, no 3, pp 173–258, 2006

Printed on acid-free paper

ISBN: 978-1-60198-018-2

Foundations and Trends® in Computer Graphics and Vision
Volume 2 Issue 3, 2006

Editorial Board

Editorial Scope

Foundations and Trends® in Computer Graphics and Vision will publish survey and tutorial articles in the following topics:

- Rendering: Lighting models; Forward rendering; Inverse rendering; Image-based rendering; Non-photorealistic rendering; Graphics hardware; Visibility computation
- Shape: Surface reconstruction; Range imaging; Geometric modelling; Parameterization;
- Mesh simplification
- Animation: Motion capture and processing; Physics-based modelling; Character animation
- Sensors and sensing
- Image restoration and enhancement
- Segmentation and grouping
- Feature detection and selection
- Color processing
- Texture analysis and synthesis
- Illumination and reflectance modeling
- Shape Representation
- Tracking
- Calibration
- Structure from motion
- Motion estimation and registration
- Stereo matching and reconstruction
- 3D reconstruction and image-based modeling
- Learning and statistical methods
- Appearance-based matching
- Object and scene recognition
- Face detection and recognition
- Activity and gesture recognition
- Image and Video Retrieval
- Video analysis and event recognition
- Medical Image Analysis
- Robot Localization and Navigation

Information for Librarians
Foundations and Trends® in Computer Graphics and Vision, 2006, Volume 2, 4 issues. ISSN paper version 1572-2740. ISSN online version 1572-2759. Also available as a combined paper and online subscription.

Foundations and Trends® in
Computer Graphics and Vision
Vol. 2, No 3 (2006) 173–258

DOI: 10.1561/0600000012

now
the essence of knowledge

Image-Based Rendering

Sing Bing Kang[1], Yin Li[2], Xin Tong[3] and Heung-Yeung Shum[4]

[1] *Microsoft Research, USA, sbkang@microsoft.com*
[2] *Microsoft Corporation, USA, yl@microsoft.com*
[3] *Microsoft Research Asia, China, xtong@microsoft.com*
[4] *Microsoft Research Asia, China, hshum@microsoft.com*

Abstract

Image-based rendering (IBR) is unique in that it requires computer graphics, computer vision, and image processing to join forces to solve a common goal, namely photorealistic rendering through the use of images. IBR as an area of research has been around for about ten years, and substantial progress has been achieved in effectively capturing, representing, and rendering scenes. In this article, we survey the techniques used in IBR. Our survey shows that representations and rendering techniques can differ radically, depending on design decisions related to ease of capture, use of geometry, accuracy of geometry (if used), number and distribution of source images, degrees of freedom for virtual navigation, and expected scene complexity.

Contents

1

Introduction

One of the primary goals in computer graphics is photorealistic rendering. Much progress has been made over the years in graphics in a bid to attain this goal, with significant advancements in 3D representations and model acquisition, measurement and modeling of object surface properties such as the bidirectional reflectance distribution function (BRDF) and surface subscattering, illumination modeling, natural objects such as plants, and natural phenomena such as water, fog, smoke, snow, and fire. More sophisticated graphics hardware that permit very fast rendering, programmable vertex and pixel shading, larger caches and memory footprints, and floating-point pixel formats also help in the cause. In other words, a variety of well-established approaches and systems are available for rendering models. See the surveys on physically based rendering [78], global illumination methods [26], and photon mapping (an extension of ray tracing) [44].

Despite all the advancements in the more classical areas of computer graphics, it is still hard to compete with images of real scenes. The rendering quality of environments in animated movies such as *Shrek 2* and even games such as *Ghost Recon* for Xbox 360$^{\text{TM}}$ is excellent, but there are hints that these environments are synthetic. Websites such

as http://www.ignorancia.org/ showcase highly photorealistic images that were generated through ray tracing, which is computationally expensive. The special effects in high-budget movies blend seamlessly in real environments, but they typically involved many man-hours to create and refine. The observation that full photorealism is really hard to achieve with conventional 3D and model-based graphics has led researchers to take a "short-cut" by working directly with real images. This approach is called *image-based modeling and rendering*. Some of the special effects used in the movie industry were created using image-based rendering techniques described in this article.

Image-based modeling and rendering techniques have received a lot of attention as a powerful alternative to traditional geometry-based techniques for image synthesis. These techniques use images rather than geometry as the main primitives for rendering novel views. Previous surveys related to image-based rendering (IBR) have suggested characterizing a technique based on how image-centric or geometry-centric it is. This has resulted in the image-geometry continuum (or *IBR continuum*) of image-based representations [52, 46].

References

[1] E. H. Adelson and J. R. Bergen, "The plenoptic function and elements of early vision," *Computational Models of Visual Processing*, pp. 3–20, 1991.

[2] A. Agarwala, C. Zheng, C. Pal, M. Agrawala, M. Cohen, B. Curless, D. Salesin, and R. Szeliski, "Panoramic video textures," in *Proceedings of SIGGRAPH (ACM Transactions on Graphics)*, August 2005.

[3] D. G. Aliaga and I. Carlbom, "Plenoptic stitching: A scalable method for reconstructing 3D interactive walkthroughs," *Computer Graphics (SIGGRAPH)*, pp. 443–450, August 2001.

[4] S. Avidan and A. Shashua, "Novel view synthesis in tensor space," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Juan, Puerto Rico), pp. 1034–1040, June 1997.

[5] S. Baker, R. Szeliski, and P. Anandan, "A layered approach to stereo reconstruction," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Santa Barbara), pp. 434–441, June 1998.

[6] R. C. Bolles, H. H. Baker, and D. H. Marimont, "Epipolar-plane image analysis: An approach to determining structure from motion," *International Journal of Computer Vision*, vol. 1, pp. 7–55, 1987.

[7] M. Botsch, A. Hornung, M. Zwicker, and L. Kobbelt, "High-quality surface splatting on today's GPUs," in *Proceedings of the Eurographics Symposium on Point-Based Graphics*, pp. 17–24, 2005.

[8] C. Buehler, M. Bosse, L. McMillan, S. Gortler, and M. Cohen, "Unstructured lumigraph rendering," in *Computer Graphics (SIGGRAPH)*, (Los Angeles, CA), pp. 425–432, August 2001.

[9] E. Camahort, "4D light-field modeling and rendering," Tech. Rep. TR01-52, The University of Texas at Austin, May 2001.

[10] E. Camahort, A. Lerios, and D. Fussell, "Uniformly sampled light fields," in *9th Eurographics Workshop on Rendering*, (Vienna, Austria), pp. 117–130, June/July 1998.

[11] F. M. Candocia, "Simultaneous homographic and comparametric alignment of multiple exposure-adjusted pictures of the same scene," *IEEE Transactions on Image Processing*, vol. 12, no. 12, pp. 1485–1494, December 2003.

[12] D. Capel and A. Zisserman, "Super-resolution from multiple views using learnt image models," in *Conference on Computer Vision and Pattern Recognition*, (Kauai, HI), vol. 2, pp. 627–634, December 2001.

[13] J.-X. Chai, S. B. Kang, and H.-Y. Shum, "Rendering with non-uniform approximate concentric mosaics," in *3D Structure from Multiple Images of Large-Scale Environments (SMILE)*, (Dublin, Ireland), pp. 94–108, July 2000.

[14] J.-X. Chai, X. Tong, S.-C. Chan, and H.-Y. Shum, "Plenoptic sampling," *Computer Graphics (SIGGRAPH)*, pp. 307–318, July 2000.

[15] C. Chang, G. Bishop, and A. Lastra, "LDI tree: A hierarchical representation for image-based rendering," *Computer Graphics (SIGGRAPH)*, pp. 291–298, August 1999.

[16] B. Chen, E. Ofek, H.-Y. Shum, and M. Levoy, "Interactive deformation of light fields," in *Symposium on Interactive 3D Graphics and Games (I3D)*, (Washington, D.C.), pp. 139–146, 2005.

[17] S. Chen and L. Williams, "View interpolation for image synthesis," *Computer Graphics (SIGGRAPH)*, pp. 279–288, August 1993.

[18] S. E. Chen, "QuickTime VR – An image-based approach to virtual environment navigation," *Computer Graphics (SIGGRAPH)*, pp. 29–38, August 1995.

[19] L. Coconu and H.-C. Hege, "Hardware-accelerated point-based rendering of complex scenes," in *Eurographics Workshop on Rendering*, (Aire-la-Ville, Switzerland), pp. 43–52, 2002.

[20] R. T. Collins, "A space-sweep approach to true multi-image matching," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Francisco), pp. 358–363, June 1996.

[21] H. S. M. Coxeter, *Introduction to Geometry*. John Wiley and Sons, 1969.

[22] J. Davis, "Mosaics of scenes with moving objects," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Santa Barbara, CA), pp. 354–360, June 1998.

[23] P. Debevec, Y. Yu, and G. Borshukov, "Efficient view-dependent image-based rendering with projective texture-mapping," in *Eurographics Workshop on Rendering*, pp. 105–116, 1998.

[24] P. E. Debevec, C. J. Taylor, and J. Malik, "Modeling and Rendering Architecture from photographs: A hybrid geometry- and image-based approach," *Computer Graphics (SIGGRAPH)*, pp. 11–20, August 1996.

[25] X. Decoret, F. Durand, F. X. Sillion, and J. Dorsey, "Billboard clouds for extreme model simplification," *Proceedings of SIGGRAPH (ACM Transactions on Graphics)*, pp. 689–696, July 2003.

[26] P. Dutré, P. Bekaert, and K. Bala, *Advanced Global Illumination*. Natick, MA: AK Peters, 2003.

[27] O. Faugeras, *Three-dimensional Computer Vision: A Geometric Viewpoint*. Cambridge, MA: MIT Press, 1993.

[28] O. Faugeras, L. Robert, S. Laveau, G. Csurka, C. Zeller, C. Gauclin, and I. Zoghlami, "3-D reconstruction of urban scenes from image sequences," *Computer Vision and Image Understanding*, vol. 69, no. 3, pp. 292–309, March 1998.

[29] M. A. Fischler and R. C. Bolles, "Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography," *Communications of the ACM*, vol. 24, no. 6, pp. 381–395, June 1981.

[30] A. Fitzgibbon, Y. Wexler, and A. Zisserman, "Image-based rendering using image-based priors," in *International Conference on Computer Vision*, vol. 2, pp. 1176–1183, 2003.

[31] D. B. Goldman and J.-H. Chen, "Vignette and exposure calibration and compensation," in *International Conference on Computer Vision*, (Beijing, China), pp. 899–906, October 2005.

[32] S. J. Gortler, R. Grzeszczuk, R. Szeliski, and M. F. Cohen, "The lumigraph," in *Computer Graphics (SIGGRAPH)*, (New Orleans), pp. 43–54, August 1996.

[33] N. Greene and P. S. Heckbert, "Creating raster Omnimax images from multiple perspective views using the Elliptical Weighted Average filter," *IEEE Computer Graphics and Applications*, vol. 6, no. 6, pp. 21–27, June 1986.

[34] G. Guennebaud and M. Paulin, "Efficient screen space approach for hardware accelerated surfel rendering," in *Workshop on Vision, Modeling, and Visualization*, pp. 1–10, 2003.

[35] R. Gupta and R. Hartley, "Linear pushbroom cameras," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 19, no. 9, pp. 963–975, September 1997.

[36] M. Halle, "Multiple viewpoint rendering," *Computer Graphics (SIGGRAPH)*, pp. 243–254, July 1998.

[37] R. Hartley and A. Zisserman, *Multiple View Geometry in Computer Vision*. Cambridge University Press, Second Edition, 2004.

[38] P. S. Heckbert, "Survey of texture mapping," *IEEE Computer Graphics and Applications*, vol. 11, no. 6, pp. 56–67, November 1986.

[39] W. Heidrich, H. Lensch, M. F. Cohen, and H.-P. Seidel, "Light field techniques for reflections and refractions," in *Eurographics Rendering Workshop*, pp. 195–375, June 1999.

[40] B. Heigl, R. Koch, M. Pollefeys, J. Denzler, and L. Van Gool, "Plenoptic modeling and rendering from image sequences taken by hand-held camera," in *DAGM*, pp. 94–101, 1999.

[41] I. Ihm, S. Park, and R. Lee, "Rendering of spherical light fields," in *Pacific Graphics*, (Seoul, Korea), pp. 59–68, October 1997.

[42] M. Irani and S. Peleg, "Improving resolution by image registration," *Graphical Models and Image Processing*, vol. 53, no. 3, pp. 231–239, May 1991.

[43] A. Isaksen, L. McMillan, and S. Gortler, "Dynamically reparameterized light fields," *Computer Graphics (SIGGRAPH)*, pp. 297–306, July 2000.

[44] H. W. Jensen, *Realistic Image Synthesis Using Photon Mapping*. A K Peters Ltd., 2001.

[45] S. Jeschke, M. Wimmer, and H. Schumann, "Layered environment-map impostors for arbitrary scenes," in *Proceedings of Graphics Interface*, pp. 1–8, May 2002.

[46] S. B. Kang, "A survey of image-based rendering techniques," in *Videometrics VI (SPIE International Symposium on Electronic Imaging: Science and Technology)*, (San Jose, CA), vol. 3641, pp. 2–16, January 1999.

[47] S. B. Kang and R. Szeliski, "Extracting view-dependent depth maps from a collection of images," *International Journal of Computer Vision*, vol. 58, no. 2, pp. 139–163, July 2004.

[48] S. B. Kang, R. Szeliski, and J. Chai, "Handling occlusions in dense multi-view stereo," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Kauai, HI), vol. I, pp. 103–110, December 2001.

[49] A. Katayama, K. Tanaka, T. Oshino, and H. Tamura, "A viewpoint dependent stereoscopic display using interpolation of multi-viewpoint images," in *Stereoscopic Displays and Virtual Reality Systems II (SPIE)*, (S. Fisher, J. Merritt, and B. Bolas, eds.), vol. 2409, pp. 11–20, 1995.

[50] L. Kobbelt and M. Botsch, "A survey of point-based techniques in computer graphics," *Computers and Graphics*, vol. 28, no. 6, pp. 801–814, 2004.

[51] S. Laveau and O. D. Faugeras, "3-D scene representation as a collection of images," in *International Conference on Pattern Recognition*, (Jerusalem, Israel), vol. A, pp. 689–691, October 1994.

[52] J. Lengyel, "The convergence of graphics and vision," *IEEE Computer*, vol. 31, no. 7, pp. 46–53, 1998.

[53] M. Levoy and P. Hanrahan, "Light field rendering," *Computer Graphics (SIGGRAPH)*, pp. 31–42, August 1996.

[54] M. Levoy and T. Whitted, "The use of points as a display primitive," Tech. Rep., UNC Technical Report 85-022, University of North Carolina, Chapel Hill, NC, 1985.

[55] M. Lhuillier and L. Quan, "Image interpolation by joint view triangulation," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Fort Collins, CO), vol. 2, pp. 139–145, June 1999.

[56] M. Lhuillier and L. Quan, "Image-based rendering by joint view triangulation," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 13, no. 11, pp. 1051–1063, November 2003.

[57] S. Lin, Y. Li, S. B. Kang, X. Tong, and H.-Y. Shum, "Simultaneous separation and depth recovery of specular reflections," in *European Conference on Computer Vision*, (Copenhagen, Denmark), vol. 3, pp. 210–224, May/June 2002.

[58] D. Lischinski and A. Rappoport, "Image-based rendering for non-diffuse synthetic scenes," in *Eurographics Rendering Workshop*, pp. 301–314, June 1998.

[59] M. Magnor and B. Girod, "Model-based coding of multi-viewpoint imagery," in *SPIE Visual Communication and Image Processing*, (Perth, Australia), vol. 4067(2), pp. 14–22, June 2000.

[60] J. Mairal and R. Keriven, "A GPU implementation of variational stereo," Tech. Rep. Research Report 05-13, CERTIS, November 2005.

[61] S. Mann, "Pencigraphy with AGC: Joint parameter estimation in both domain and range of functions in same orbit of the projective-Wyckoff group," in *International Conference on Image Processing*, (Los Alamitos, CA), vol. 3, pp. 193–196, 1996.

[62] S. Mann and R. W. Picard, "Virtual bellows: Constructing high-quality images from video," in *International Conference on Image Processing*, (Austin, TX), vol. I, pp. 363–367, November 1994.

[63] W. Mark, L. McMillan, and G. Bishop, "Post-rendering 3D Warping," in *Symposium on I3D Graphics*, pp. 7–16, April 1997.

[64] W. Matusik, C. Buehler, R. Raskar, S. Gortler, and L. McMillan, "Image-based visual hulls," *Computer Graphics (SIGGRAPH)*, pp. 369–374, July 2000.

[65] W. Matusik, H. Pfister, P. Ngan, P. Beardsley, R. Ziegler, and L. McMillan, "Image-based 3D photography using opacity hulls," *Proceedings of SIGGRAPH (ACM Transactions on Graphics)*, pp. 427–437, July 2002.

[66] L. McMillan, "An image-based approach to three-dimensional computer graphics," Tech. Rep., Ph.D. Dissertation, UNC Computer Science TR97-013, 1999.

[67] L. McMillan and G. Bishop, "Head-tracked stereoscopic display using image warping," in *Stereoscopic Displays and Virtual Reality Systems II (SPIE)*, pp. 21–30, February 1995.

[68] L. McMillan and G. Bishop, "Plenoptic modeling: An image-based rendering system," *Computer Graphics (SIGGRAPH)*, pp. 39–46, August 1995.

[69] V. S. Nalwa, "A true omnidirectional viewer," Tech. Rep., Bell Laboratories, Holmdel, NJ, February 1996.

[70] S. K. Nayar, "Catadioptric omnidirectional camera," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Juan, Puerto Rico), pp. 482–488, June 1997.

[71] R. Ng, "Fourier slice photography," *Proceedings of SIGGRAPH (ACM Transactions on Graphics)*, vol. 24, no. 3, pp. 735–744, July 2005.

[72] M. M. Oliveira, G. Bishop, and D. McAllister, "Relief texture mapping," in *Computer Graphics (SIGGRAPH)*, (New Orleans, LA), pp. 359–368, July 2000.

[73] J. D. Owens, D. Luebke, N. Govindaraju, M. Harris, J. Kruger, A. E. Lefohn, and T. J. Purcell, "A survey of general-purpose computation on graphics hardware," in *Eurographics, State of the Art Reports*, pp. 21–51, August 2005.

[74] S. Peleg and M. Ben-Ezra, "Stereo panorama with a single camera," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Fort Collins, CO), pp. 395–401, June 1999.

[75] S. Peleg and J. Herman, "Panoramic mosaics by manifold projection," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Juan, Puerto Rico), pp. 338–343, June 1997.

[76] S. Peleg, B. Rousso, A. Rav-Acha, and A. Zomet, "Mosaicing on adaptive manifolds," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, pp. 1144–1154, October 2000.

[77] H. Pfister, M. Zwicker, J. van Baar, and M. Gross, "Surfels: Surface elements as rendering primitives," in *Computer Graphics (SIGGRAPH)*, pp. 335–342, July 2000.

[78] M. Pharr and G. Humphreys, *Physically Based Rendering*. Morgan Kaufmann, 2004.

[79] F. Policarpo, M. M. Oliveira, and J. L. D. Comba, "Real-time relief mapping on arbitrary polygonal surfaces," in *ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games*, April 2005.

[80] D. Porquet, J.-M. Dischler, and D. Ghazanfarpour, "Real-time high quality view-dependent texture mapping Using per-pixel visibility," in *International Conference on Computer Graphics and Interactive Techniques in Australasia and Southeast Asia (Graphite)*, November/December 2005.

[81] T. Porter and T. Duff, "Compositing digital images," in *Computer Graphics (SIGGRAPH)*, pp. 253–259, July 1984.

[82] K. Pulli, M. Cohen, T. Duchamp, H. Hoppe, J. McDonald, L. Shapiro, and W. Stuetzle, "View-based rendering: Visualizing real objects from scanned range and color data," in *Eurographics Workshop on Rendering*, (St. Etienne, France), June 1997.

[83] P. Rademacher and G. Bishop, "Multiple-center-of-projection images," in *Computer Graphics (SIGGRAPH)*, (Orlando, FL), pp. 199–206, July 1998.

[84] A. Rav-Acha, Y. Pritch, D. Lischinski, and S. Peleg, "Dynamosaicing: Video mosaics with non-chronological time," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Diego, CA), pp. 58–65, June 2005.

[85] M. J. P. Regan, G. S. P. Miller, S. M. Rubin, and C. Kogelnik, "A real-time low-latency hardware light-field renderer," in *Computer Graphics (SIGGRAPH)*, (Los Angeles, CA), pp. 287–290, August 1999.

[86] L. Ren, H. Pfister, and M. Zwicker, "Object space EWA surface splatting: A hardware accelerated approach to high quality point rendering," *Eurographics, Computer Graphics Forum*, vol. 21, no. 3, pp. 461–470, 2002.

[87] M. Sainz and R. Pajarola, "Point-based rendering techniques," *Computers and Graphics*, vol. 28, no. 6, pp. 869–879, 2004.

[88] D. Scharstein, "Stereo vision for view synthesis," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Francisco, CA), pp. 852–857, June 1996.

[89] G. Schaufler, "Per-object image warping with layered impostors," in *Eurographics Workshop on Rendering*, pp. 145–156, June/July 1998.

[90] A. Schödl, R. Szeliski, D. H. Salesin, and I. Essa, "Video textures," in *Computer Graphics (SIGGRAPH)*, (New Orleans, LA), pp. 489–498, July 2000.

[91] S. M. Seitz and C. M. Dyer, "View morphing," in *Computer Graphics (SIGGRAPH)*, (New Orleans, LA), pp. 21–30, August 1996.

[92] S. M. Seitz and K. N. Kutulakos, "Plenoptic image editing," in *International Conference on Computer Vision*, pp. 17–24, 1998.

[93] J. Shade, S. Gortler, L.-W. He, and R. Szeliski, "Layered depth images," in *Computer Graphics (SIGGRAPH)*, (Orlando), pp. 231–242, July 1998.

[94] H.-Y. Shum, S.-C. Chan, and S. B. Kang, *Image-Based Rendering*. Springer, 2006.

[95] H.-Y. Shum and L.-W. He, "Rendering with concentric mosaics," in *Computer Graphics (SIGGRAPH)*, (Los Angeles), pp. 299–306, August 1999.

[96] H.-Y. Shum, J. Sun, S. Yamazaki, Y. Li, and C. K. Tang, "Pop-up light field: An interactive image-based modeling and rendering system," *ACM Transactions on Graphics*, vol. 23, no. 2, pp. 143–162, April 2004.

[97] H.-Y. Shum and R. Szeliski, "Construction and refinement of panoramic mosaics with global and local alignment," in *International Conference on Computer Vision*, (Bombay, India), pp. 953–958, January 1998.

[98] H.-Y. Shum, L. Wang, J.-X. Chai, and X. Tong, "Rendering by manifold hopping," *International Journal of Computer Vision*, vol. 50, no. 2, pp. 185–201, 2002.

[99] P. P. Sloan, M. F. Cohen, and S. J. Gortler, "Time critical lumigraph rendering," in *Symposium on Interactive 3D Graphics*, (Providence, RI), pp. 17–23, April 1997.

[100] R. Swaminathan, S. B. Kang, R. Szeliski, A. Criminisi, and S. K. Nayar, "On the motion and appearance of specularities in image sequences," in *European Conference on Computer Vision*, (Copenhagen, Denmark), vol. 1, pp. 508–523, May/June 2002.

[101] R. Szeliski, "Video mosaics for virtual environments," *IEEE Computer Graphics and Applications*, pp. 22–30, March 1996.

[102] R. Szeliski, S. Avidan, and P. Anandan, "Layer extraction from multiple images containing reflections and transparency," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Hilton Head Island, NC), pp. 246–253, June 2000.

[103] R. Szeliski and M. Cohen, "Sprites with depth–fast rendering techniques for sprites with depth offsets," Tech. Rep., Microsoft Research Vision Technology Group, Technical Note No. 5, 1998.

[104] R. Szeliski and H.-Y. Shum, "Creating full view panoramic image mosaics and environment maps," *Computer Graphics (SIGGRAPH)*, pp. 251–258, August 1997.

[105] Y. Tsin, S. B. Kang, and R. Szeliski, "Stereo matching with reflections and translucency," in *IEEE Conference on Computer Vision and Pattern Recognition*, (Madison, WI), vol. 1, pp. 702–709, June 2003.

[106] M. Uyttendaele, A. Criminisi, S. B. Kang, S. Winder, R. Hartley, and R. Szeliski, "High-quality image-based interactive exploration of real-world environments," *IEEE Computer Graphics and Applications*, vol. 24, no. 3, pp. 52–63, May/June 2004.

[107] M. Uyttendaele, A. Eden, and R. Szeliski, "Eliminating ghosting and exposure artifacts in image mosaics," in *IEEE Conference on Computer Vision and Pattern Recognition*, vol. 2, pp. 509–516, December 2001.

[108] B. Wallace, "Merging and transformation of raster images for cartoon animation," in *Computer Graphics (SIGGRAPH)*, (Dallas, TX), pp. 253–262, 1981.

[109] T. Whitted, "Overview of IBR: Software and hardware issues," in *International Conference on Image Processing*, (Vancouver, Canada), vol. 2, p. 14, September 2000.

[110] J. Woetzel and R. Koch, "Real-time multi-stereo depth estimation on GPU with approximative discontinuity handling," in *1st European Conference on Visual Media Production (CVMP)*, (London, UK), March 2004.

[111] T. Wong, P. Heng, S. Or, and W. Ng, "Image-based rendering with controllable illumination," in *Eurographics Workshop on Rendering*, (St. Etienne, France), pp. 13–22, June 1997.

[112] D. N. Wood, D. I. Azuma, K. Aldinger, B. Curless, T. Duchamp, D. H. Salesin, and W. Stuetzle, "Surface light fields for 3D photography," in *Computer Graphics (SIGGRAPH), Annual Conference Series*, (New Orleans, LA), pp. 287–296, July 2000.

[113] D. N. Wood, A. Finkelstein, J. F. Hughes, C. E. Thayer, and D. H. Salesin, "Multiperspective panoramas for cel animation," in *Computer Graphics (SIGGRAPH)*, (Los Angeles, CA), pp. 243–250, August 1997.

[114] O. Woodford and A. Fitzgibbon, "Fast image-based rendering using hierarchical image-based priors," in *British Machine Vision Conference*, (Oxford, UK), September 2005.

[115] Y. Xiong and K. Turkowski, "Creating image-based VR using a self-calibrating fisheye lens," in *IEEE Conference on Computer Vision and Pattern Recognition*, (San Juan, Puerto Rico), pp. 237–243, June 1997.

[116] R. Yang, G. Welch, and G. Bishop, "Real-time consensus-based scene reconstruction using commodity graphics hardware," in *Pacific Graphics*, (Beijing, China), pp. 225–234, 2002.

[117] Z. Zhang, L. Wang, B. Guo, and H.-Y. Shum, "Feature-based light field morphing," *Proceedings of SIGGRAPH (ACM Transactions on Graphics)*, pp. 457–464, July 2002.

[118] J. Y. Zheng and S. Tsuji, "Panoramic representation for route recognition by a mobile robot," *International Journal of Computer Vision*, vol. 9, pp. 55–76, 1992.

[119] A. Zomet, D. Feldman, S. Peleg, and D. Weinshall, "Mosaicing new views: The crossed-slits projection," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 25, no. 6, pp. 741–754, June 2003.