Raport Badawczy

Research Report

RB/43/2016

Content-based image retrieval tools and techniques

T. Jaworska

Instytut Badań Systemowych
Polska Akademia Nauk

Systems Research Institute
Polish Academy of Sciences

POLSKA AKADEMIA NAUK

Instytut Badań Systemowych

ul. Newelska 6

01-447 Warszawa

tel.: (+48) (22) 3810100

fax: (+48) (22) 3810105

Kierownik Zakładu zgłaszający pracę:
Prof. dr hab. inż. Janusz Kacprzyk

Warszawa 2016

Tatiana Jaworska

Content-Based Image Retrieval Tools and Techniques

In the beginning was an image.

To my mother
who inspired me
to develop intellectually

Contents

11 Conclusions

11.1 Final Remarks

In contrast with the early years (Section 1.1), we have witnessed a major shift from global feature representations for images, such as colour histograms and global shape descriptors, to local features and descriptors, such as salient points, region-based features, spatial model features, robust local shape characterizations and deep learning. It is not hard to imagine this shift to have been triggered by a realization that the image domain is too deep for global features to reduce the semantic gap. Local features often correspond with more meaningful image components, such as rigid objects and entities, which make association of semantics with image portions straightforward.

Many years of research have made it clear that emulating human vision is very challenging, nonetheless, practical approaches can help to build useful systems. While the endeavour to characterize vision will likely continue, particularly in the core field of computer vision, practical approaches (e.g., fusion of local and global representations for top-down as well as bottom-up representations) will potentially improve retrieval performance and user satisfaction in such systems. The availability of 3D and stereo image data should be exploited to extract features more coherent to the human vision system. In summary, reducing the sensorial gap in tandem with the semantic gap should continue to be a goal for the future.

All the time we expect that computers will operate with images as effectively as humans. There have appeared works which compared and tried to evaluate which tasks in terms of image processing better complete a computer than a man [278].

11.2 Future Challenges and Open Problems

In spite of many aspects have been covered so far, a number of substantial problems remain. The prime task is to find better ways of modelling human similarity perception at the high-level features as we have signalized in sect. 2.2.

The next aspect is to effectively improve retrieval beginning from the improvement of methods of query formulation and refinement and ending on the results presentation [275].

Additionally, depending on the scale of the key content or pattern, an appropriate representation should be chosen. In this sense, hybrid representations may sometimes be more attractive, but this may come at the cost of additional complexity. While segmentation is intended to recognize objects in a scene, precise segmentation still remains an open problem. Therefore, alternative approaches to characterize structure may be more suitable. However, such a representation may lose the charm of clear interpretability. Among the different approaches to segmentation, there is often a trade-off between quality and complexity which might lead to a difference in the eventual search performance and speed. Hence, the choice of image signature to be used should depend on the desirability of the system [275].

The subjectivity in similarity needs to be incorporated more rigorously into image similarity measures, to achieve what can be called a personalized image search. This can also potentially incorporate ideas beyond the semantics, such as aesthetics and personal preferences in style and content.

A long-term goal of research should therefore also include the ability to render high-resolution, high-dimension, and high-throughput images searchable by content. Meanwhile, we do hope that the quest for robust and reliable image understanding technology will continue. The future of CBIR depends a lot on the collective focus and overall progress in each aspect of image retrieval, and how much the average individual stands to benefit from it.

Although we can manage with the simpler cases, there still remain many open problems:

- in terms of features, we move from the low features, understood by computer, to the high ones, perceived by the humans:
  - Low – level
  - Middle – level
  - High – level
- in terms of media, the more complicated content the more information is provided by the media :
  - Image
  - Video
  - Website
  - 3D object
- in terms of the matching strategy, we have commenced from target searching among images and now we tend to retrieve images semantically:
  - Target searching
  - Similarity searching
  - Semantic retrieval

There are still many images impossible to segment Fig. 11.**1** a) – colour layout causes a fragment of the roof to be divided into many inconsistent fragments, classification Fig. 11.**1** b) – many details generate ambiguous or false classification, interpretation (reality and image reality) Fig. 11.1 c) - the problem of "image into image" has not been solved by the AI community yet, or similarity Fig. 11.1 d) – semantically all these images present a swan, but the shape differences are too big to show them as similar objects.

a) b) c) d)

Fig. 11.1 Examples of images which remain open problems in CBIR.

Finally, an important problem little discussed in the literature but of much importance, is the validation of retrieval results. For example, how can we justify calling one set of shape retrieval results better than another? How can we compare results among different shape representations and similarity measures? We addressed this problem in sect. 7.2 and described the obtained results (subsect. 9.9.1) because still images are evaluated based on the universal image similarity index (SSIM).

The validation of the query results in either a quantitative sense or with a non-quantitative approach that will justify confidence in the results using a particular method remains a critical issue for many works.

Generally speaking, future trends lead towards the unification of image services. It means that, for instance, the user will send their new sets of images, privately or professionally, to an already trained cloud which will offer classification services. These image services will function for different users like contemporary plug-and-play services.

In the distant future images and videos will be processed and retrieved using quantum computers, which will change our understanding of systems in terms of time and complexity of algorithms. In means that whole DBs comprising images in a high resolution will be analysed simultaneously.

References

[1] Y. Yao, Y. Zeng, N. Zhong and X. Huang, "Knowledge Retrieval," in *Proceedings of the 2007 IEEE/WIC/ACM International Conference on Web Intelligence*, Silicon Valley, USA, 2007.

[2] "http archive," 2016. [Online]. Available: http://httparchive.org/trends.php?s=Top1000&minlabel=Jan+20+2011&maxlabel=Oct+15+2014#bytesImg&reqImg.

[3] S. Nandagopalan, B. S. Adiga and N. Deepak, "A Universal Model for Content-Based Image Retrieval," *World Academy of Science, Engineering and Technology,* vol. 46, pp. 644-647, 2008.

[4] M. Yasmin, S. Mohsin, I. Irum and M. Sharif, "Content Based Image Retrieval by Shape, Color and Relevance Feedback," *Life Science Journal,* vol. 10, no. 4s, pp. 593-598, 2013.

[5] M. Rehman, M. Iqbal, M. Sharif and M. Raza, "Content Based Image Retrieval: Survey," *World Applied Sciences Journal,* vol. 19, no. 3, pp. 404-412, 2012.

[6] Y. J. Lee, . L. C. Zitnick and M. F. Cohen, "ShadowDraw: Real-time User Guidance for Freehand Drawing.," *ACM Transactions on Graphics (TOG),,* vol. 30, no. 4, pp. 1-27, July 2011.

[7] T. M. Lehmann, M. O. Güld, C. Thies, B. Fischer, D. Keysers, K. Spitzer, H. Ney, M. Kohnen, H. Schubert and B. B. Wein, "Content-Based Image Retrieval in Medical Applications," *Methods on Imformatic in Medicine,* vol. 43, pp. 354-361, 2004.

[8] S. Antani, J. Cheng, J. Long, R. L. Long and G. R. Thoma, "Medical Validation and CBIR of Spine X-ray Images over the Internet," in *Proceedings of IS&T/SPIE Electronic Imaging. Internet Imaging VII*, San Jose, C, 2006.

[9] R. K. Srihari, "Automatic Indexing and Content-Based Retrieval of Captioned Images," *IEEE Computer,* vol. 28, no. 9, pp. 49-56, September 1995.

[10] V. Khanaa, M. Rajani, K. Ashok and A. Raj, "Efficient Use of Semantic Annotation in Content Based Image Retrieval (CBIR)," *International Journal of Computer Science Issues,* vol. 9, no. 2, pp. 273-279, March 2012.

[11] C. Carson, S. Belongie, H. Greenspan and J. Malik, "Blobworld: Image Segmentation Using Expectation-Maximization and Its Application to Image Querying," *IEEE Transaction on Pattern Analysis and Machine Intellignece,* vol. 24, no. 8, pp. 1026-1038, Aug. 2002.

[12] Y. Rubner, C. Tomasi and L. J. Guibas , "The Earth Mover's Distance as a Metric for Image Retrieval," *International Journal of Computer Vision,* vol. 40, no. 2, pp. 99-121, 2000.

[13] B. Xiao , X. Gao, D. Tao i X. Li, „Recognition of Sketches in Photos," w *Multimedia Analysis, Processing and Communications*, tom 346, W. Lin, D. Tao, J. Kacprzyk , Z. Li, E. Izquierdo i H. Wang , Redaktorzy, Berlin, Springer-Verlag, 2011, pp. 239-262.

[14] T. Kato, "Database architecture for content-based image retrieval," in *Proceedings of SPIE Image Storage and Retrieval System*, San Jose, CA, USA, 1992, April,.

[15] V. N. Gudivada and V. V. Raghavan , "Content-Based Image Retrieval Systems," *IEEE Computer,* vol. 28, no. 9, pp. 18-22, Sep. 1995.

[16] M. Flickner, H. Sawhney, W. Niblack , J. Ashley, Q. Huang, B. Dom, M. Gorkani , J. Hafner, D. Lee, D. Petkovic, D. Steele and P. Yanker , "Query by Image and Video Content: The QBIC System," *IEEE Computer*, vol. 28, no. 9, pp. 23-32, September 1995.

[17] V. E. Ogle and M. Stonebraker, "CHABOT: Retrieval from a Relational Database of Images," *IEEE Computer*, vol. 28, no. 9, pp. 40-48, September 1995.

[18] R. Mehrotra and J. E. Gary, "Similar-Shape Retrieval in Shape Data Management," *IEEE Computer*, vol. 28, no. 9, pp. 57-62, Sep. 1995.

[19] M. Nakazato i T. S. Huang, „3D MARS: Immersive Virtual Reality for Content-Based Image Retrieval," w *IEEE International Conference on Multimedia and Expo*, Tokyo, August 22-25, 2001.

[20] S. Saurin, „Saurin Shah Portfolio," 2014. [Online]. Available: http://www.shahsaurin.com/projects_demo/threejs-webgl/ .

[21] G. Chang, M. J. Healey , J. A. M. McHugh i J. T. L. Wang, Mining the World Wide Web: An Information Search Approach., Norwell: Kluwer Academic, 2001.

[22] T. Jaworska, „Object extraction as a basic process for content-based image retrieval (CBIR) system.," *Opto-Electronics Review*, tom 15, nr 4, pp. 184-195, Dec. 2007.

[23] D. G. Lowe, "Distinctive Image Features from Scale-Invariant Keypoints," *Internationa Journal of Computer Vision*, vol. 60, no. 2, pp. 91-110, 2004.

[24] D. G. Lowe, "Object Recognition from local scale-invariant features," in *International Conferences on Computer Vision*, Corfu, Greece, 1999.

[25] . C. Leininger , „Fusion d'images : des outils au service des neurochirurgiens," June 2006. [Online]. Available: https://interstices.info/jcms/c_16870/fusion-d-images-des-outils-au-service-des-neurochirurgiens.

[26] M. R. Azimi-Sadjadi, J. Salazar and S. Srinivasan, "An Adaptable Image Retrieval System With Relevance Feedback Using Kernel Machines and Selective Sampling," *IEEE Transactions on Image Processing*, vol. 18, no. 7, p. 1645 1659, 2009.

[27] J. Urban, J. M. Jose and C. J. van Rijsbergen, "An adaptive technique for content-based image retrieval," *Multimedial Tools Applied*, no. 31, pp. 1-28, July 2006.

[28] X. S. Zhou and T. S. Huang, "Relevance Feedback in Image Retrieval: A Comprehensive Review," *ACM Multimedia Systems*, vol. 8, no. 6, pp. 536-544, 2003.

[29] L. Zhang, L. Wang and W. Lin, "Conjunctive patches subspace learning with side information for collaborative image retrieval," *IEEE Transactions on Image Processing*, vol. 21, no. 8, pp. 3707-3720, 2012.

[30] M. M. Rahman, S. K. Antani and G. R. Thoma, "A query expansion framework in image retrieval domain based on local and global analysis," *Information Processing and Management*, vol. 47, pp. 676-691, 2011.

[31] L. Zhang, L. Wang and W. Lin, "Generalized biased discriminant analysis for content-based image retrieval," *IEEE Transactions on System, Man, Cybernetics, Part B - Cybernetics*, vol. 42, no. 1, pp. 282-290, 2012.

[32] L. Zhang, L. Wang and W. Lin, "Semi-supervised biased maximum margin analysis for interactive image retrieval," *IEEE Transactions on Image Processing*, vol. 21, no. 4, pp. 2294-2308, 2012.

[33] L. Wang, W. Lin and L. Zhang, "Geometric Optimum Experimental Design for Collaborative Image Retrieval," *IEEE Transactions on Circuits and System for Video Technology*, vol. 24, pp. 346-359, 2014.

[34] F. Long, H. Zhang and D. D. Feng, "Fundamentals of content-based image retrieval," in *Multimedia Information Retrieval and Management Technological Fundamentals and Applications.*, New York, Sprainger-Verlag, 2003, pp. 1-26.

[35] S. Gould and X. He, "Scene Understanding by labellilng Pixels," *Communications of the ACM,* vol. 57, no. 11, pp. 68-77, November 2014.

[36] J. Yao, S. Fidler and R. Urtasun, "Describing the Scene as a Whole: Joint Object Detection, Scene Classification and Semantic Segmentation," in *The 26th IEEE Conference on Computer Vision and Pattern Recognition*, Providence, Rhode Island, 2012.

[37] L.-J. Li, H. Su, . E. P. Xing and L. Fei-Fei, "Object Bank: A High-Level Image Representation for Scene Classification and Semantic Feature Sparsification," in *24th Annual Conference on Neural Information Processing Systems* , Vancouver, Canada, 2010.

[38] D. M. Wells, A. P. French, A. Naeem, O. Ishaq and R. Traini, "Recovering the dynamics of root growth and development using novel image acquisition and analysis methods," *Phisiological Transactions of The Royal Society B,* no. 367, p. 1517–1524, 2012.

[39] C. Steger, M. Ulrich and C. Wiedemann, Machine Vision Algorithms and Applications, Weinheim: Wiley-VCH, 2008.

[40] J. Wan, D. Wang, S. C. Hoi, P. Wu, J. Zhu, Y. Zhang and J. Li, "Deep Learning for Content-Based Image Retrieval: A Comprehensive Study," in *Proceedings of the ACM International Conference on Multimedia*, Orlando, Florida, 3-7 Nov. 2014.

[41] A. W. M. Smeulders, M. Worring, S. Santini, A. Gupta and R. Jain, "Content-Based Image Retrieval at the End of the Early Years," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 22, no. 12, pp. 1349-1380, Dec 2000.

[42] T. Jaworska, „A Search-Engine Concept Based on Multi-Feature Vectors and Spatial Relationship," w *Flexible Query Answering Systems*, tom 7022, H. Christiansen, G. De Tré, A. Yazici, S. Zadrożny i H. L. Larsen, Redaktorzy, Ghent, Springer, 2011, pp. 137-148.

[43] C.-R. Su, J.-J. Chen and K.-L. Chang, "Content-Based Image Retrieval on Reconfigurable Peer-to-Peer Networks," in *International Symposium on Biometrics and Security Technologies*, 2013.

[44] "List of CBIR engines," 2015. [Online]. Available: http://en.wikipedia.org/wiki/List_of_CBIR_engines.

[45] L.-J. Li, C. Wang, Y. Lim, D. M. Blei and L. Fei-Fei, "Building and Using a Semantivisual Image Hierarchy," in *IEEE Conference on Computer Vision and Pattern Recognition* , June, 2010.

[46] F. Wu, Advances in Visual Data Compression and Communication: Meeting the Requirements of New Applications, CRC Press, 2014, p. 513.

[47] J. G. Kolo, K. P. Seng, L.-M. Ang and S. R. S. Prabaharan, "Data Compression Algorithms for Visual Information," in *Informatics Engineering and Information Science*, vol. 253, A. A. Manaf, . S. Sahibuddin, . R. Ahmad , . S. M. Daud and . E. El-Qawasmeh , Eds., Berlin, Springer-Verlag, 2011, pp. 484-497.

[48] N. Sharda, "Multimedia Transmission ober Wireless Sensor Networks," in *Visual Information Processing in Wireless Sensor Networks: Technology, Trends and Applications*, L. Ang, Ed., 2011.

[49] T. Jaworska, „Object extraction as a basic process for content-based image retrieval (CBIR) system.," *Opto-Electronics Review,* tom 15, nr 4, pp. 184-195, December 2007.

[50] T. Jaworska, "Database as a Crucial Element for CBIR Systems," in *Proceedings of the 2nd International Symposium on Test Automation and Instrumentation*, Beijing, China, 16-20 Nov., 2008.

[51] T. Jaworska, "Application of Fuzzy Rule-Based Classifier to CBIR in comparison with other classifiers," in *11th International Conference on Fuzzy Systems and Knowledge Discovery*, Xiamen, China, 19-21.08.2014.

[52] T. Jaworska, "Spatial representation of object location for image matching in CBIR," in *New Research in Multimedia and Internet Systems*, vol. 314, A. Zgrzywa, K. Choroś and A. Siemiński, Eds., Wrocław, Springer, 2014, pp. 25-34.

[53] T. Jaworska, "Query techniques for CBIR," in *Flexible Query Answering Systems*, vol. 400, T. Andreasen, H. Christiansen, J. Kacprzyk, H. Larsen, G. Pasi, O. Pivert, G. De Tre, M. A. Vila, A. Yazici and S. Zadrożny, Eds., Cracow, Springer, 2015, pp. 403-416.

[54] Y.-J. Zhang, Y. Gao and Y. Luo, "Object-Based Techniques for Image Retrieval," in *Multimedia Systems and Content-Based Image Retrieval*, S. Deb, Ed., Hershey, London, IDEA Group Publishing, 2004, pp. 156-181.

[55] T. Tuytelaars and K. Mikolajczyk, "Local Invariant Feature Detectors: A Survey," *Computer Graphics and Vision*, vol. 3, no. 3, p. 177–280, 2007.

[56] W. Niblack, M. Flickner, D. Petkovic, P. Yanker, R. Barber, W. Equitz, E. Glasman, C. Faloutsos and G. Taubin, "The QBIC Project: Querying Images by Content Using Colour, Texture and Shape," *SPIE*, vol. 1908, pp. 173-187, 1993.

[57] G. Pass and R. Zabith, "Histogram refinement for content-based image retrieval," *IEEE Workshop on Applications of Computer Vision*, pp. 96-102, 1996.

[58] M. Pietikäinen, Ed., Texture Analysis in Machine Vision, vol. 40, World Scientific, 2000.

[59] N. Sebe and M. S. Lew, "Texture Features for Content-Based Retrieval," in *Principles of Visual Information Retrieval*, M. S. Lew, Ed., London , Springer Science & Business Media, 2013, pp. 50-81.

[60] M. Tuceryan and A. K. Jain, "Texture Analysis," in *The Handbook of Pattern Recognition and Computer Vision*, 2 ed., C. H. Chen, L. F. Pau and P. S. P. Wang, Eds., World Scientific Publishing Co., 1998, pp. 207-248.

[61] S. W. Zucker, "Toward a Model of Texture," *Computer Graphics and Image Processing*, vol. 5, pp. 190-202, 1976.

[62] N. Ahuja, "Dot Pattern Processing Using Voronoi Neighborhoods," *IEEE Transaction on Pattern Analysis and Machine Intelligence*, no. 4, pp. 336-343, May 1982.

[63] R. M. Haralick, "Statistical and Structural Approaches to Texture," *Proceedings of the IEEE*, vol. 67, pp. 786-804, 1979.

[64] . M. Pietikäinen, T. Ojala and D. Harwood, "A Comparative Study of Texture Measures with Classification Based on Feature Distributions.," *Pattern Recognition*, vol. 29, no. 1, pp. 51-59, January 1996.

[65] T. Ojala, M. Pietikäinen and T. Mäenpää, "Multiresolution Gray-scale and Rotation Invariant Texture Classification with Local Binary Patterns.," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 24, no. 7, pp. 971-987, 2002.

[66] M. Pietikäinen, A. Hadid, G. Zhao and T. Ahonen, Computer Vision Using Local Binary Patterns, vol. 40 in Computational Imaging and Vision, Springer Science & Business Media, 2007.

[67] H. Tamura, S. Mori i T. Yamawaki, „Texture features corresponding to visual perception," *IEEE Transactions On Systems, Man and Cybernetics*, tom 8, pp. 460-473, 1978.

[68] R. Sriram , J. M. Francos and W. A. Pearlman, "Texture coding using a Wold decomposition model.," *IEEE Transactions of Image Processing* , vol. 5, no. 9, pp. 1382-1386, 1996.

[69] G. L. Gimel'farb and A. K. Jain, "On retrieving textured images from an image data base.," *Pattern Recognition*, vol. 29, no. 9, pp. 1461-1483, 1996.

[70] A. P. Pentland, "Fractal-based description of natural scenes," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 6, no. 6, pp. 661-674., June 1984.

[71] B. B. Mandelbrot, Fractal Geometry of Nature, New York: Freeman, 1982.

[72] H. E. Hurst, "Long-term storage capacity of reservoirs," *Transactions of the American Society of Civil Engineers,* vol. 116, no. 1, pp. 770-799, 1951.

[73] S. Ezekiel and J. A. Cross, "Fractal-based Texture Analysis," in *APCC/OECC'99, Joint Conference of 5th Asia-Pacific Conference on Communications (APCC) and 4th Opto-Electronics and Communications Conference (OECC),* 1999.

[74] J. Millard, P. Augat, T. M. Link, M. Kothari, D. C. Newitt, H. K. Genant, and S. Majumdar, "Power Spectral Analysis of Vertebral Trabecular Bone Structure from Radiographs: Orientation Dependence and Correlation with Bone Mineral Density and Mechanical Properties," *Calcified Tissue International,* vol. 63, pp. 482-489, 1998.

[75] S. Selvarajah and S. R. Kodituwakku, "Analysis and Comparison of Texture Features for Content Based Image Retrieval," *International Journal of Latest Trends in Computing,* vol. 2, no. 1, pp. 108-113, March 2011.

[76] G. M. Haley and B. S. Manjunath, "Rotation-Invariant Texture Classification Using a Complete Space-Frequency Model," *IEEE Transactions on Image Processing,* vol. 8, no. 2, Feb. 1999.

[77] D. Gabor, "Theory of communication," *Journal of the Institution of Electrical Engineers* , pp. 445 - 457, 1946.

[78] T. S. Lee, "Image Representation Using 2D Gabor Wavelets," *IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE,* vol. 18, no. 10, October 1996.

[79] T. Jaworska, "Point-to-point correspondence into stereo pair of images," Silesian University of Technology, Gliwice, Poland, 2001.

[80] N. Sebe and M. S. Lew, "Wavelet Based Texture Classification," in *Proceedings. 15th International Conference on Pattern Recognition,* 2000.

[81] P. J. Burt and E. H. Adelson, "The Laplacian pyramid as a compact image code," *IEEE TRANSACTIONS ON COMMUNICATIONS,* Vols. COM-31, no. 4, pp. 532-540, April 1983.

[82] J. L. Crowley, "A representation for visual information," 1987.

[83] I. Daubechies, Ten lectures on wavelets, Philadephia: Society for Industrial and Applied Mathematics, 1992.

[84] S. Mallat, "A Theory for Multiresolution Signal Decomposition: The Wavelet Representation," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 11, no. 7, pp. 674-693, 1989.

[85] S. Mallat, "Multiresolution Approximation and Wavelet Orthonormal Bases of L2(R)," *Transactions American Mathematical Society,* vol. 315, no. 1, pp. 69-87, 1989.

[86] Y. Meyer, Les ondelettes. Algorithmes et applications, Paris: Armand Colin, 1992.

[87] P. Wojtaszczyk, Wavelet Theory (in Polish), Warsaw: PWN, 2000.

[88] S. Mallat, A wavelet tour of signal processing, Academic Press, 1998.

[89] M. Faizal, A. Fauzi and P. H. Lewis, "Automatic texture segmentation for content-based image retrieval application," *Pattern Analysis and Applications,* vol. 9, p. 307–323, 2006.

[90] R. A. Kirsch , "Computer determination of the constituent structure of biological images," *Computers and Biomedical Research,* vol. 4, no. 3, p. 315–328, July 1971.

[91] L. Vincent and P. Soille, "Watersheds in digital spaces: an efficient algorithm based on immersion simulations," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 13, no. 6, p. 583–598, 1991.

[92] O. Basir, H. Zhu and F. Karray, "Fuzzy Based Image Segmentation," in *Fuzzy Filters foe Image processing,* vol. 122, Berlin, Springer, 2003, pp. 101-128.

[93] H. M. Sobel, Multivariate Observations, Wiley, 1984.

[94] J. M. S. Prewitt, "Object Enhancement and Extraction," in *Picture Processing and Psychopictorics,*, B. S. B. S. Lipkin and A. Rosenfeld, Eds., NY, Academic Press, 1970.

[95] J. Canny, "A computational approach to edge detection," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vols. PAMI-8, no. 6, pp. 679-698, 1986.

[96] C. Xu and J. L. Prince, "Snakes, Shapes, and Gradient Vector Flow," *IEEE TRANSACTIONS ON IMAGE PROCESSING,* vol. 7, no. 3, pp. 359-369, March 1998.

[97] R. O. Duda and P. E. Hart, "Use of the HOUGH Transformation to Detect Lines and Curves in Pictires," 1971.

[98] Q. Zhu, . L. Wang, Y. Wu and J. Shi,, "Contour Context Selection for Object Detection: A Set-to-Set Contour Matching Approach,," in *The 10th European Conference on Computer Vision (ECCV)*, Marseille, France, 2008.

[99] D. Zhang and G. Lu, "Review of shape representation andd escription techniques," *Pattern Recognition,* vol. 37, p. 1 – 19, 2004.

[100] S. Abbasi, F. Mokhtarian and J. Kittler, "Curvature scale space image in shape similarity retrieval," *Multimedia Systems,* no. 7, p. 467–476, 1999.

[101] C.-J. Sze, H.-R. Tyan, H.-Y. M. Liao, C.-S. Lu and S.-K. Huang, "Shape-based Retrieval on a Fish Database of Taiwan," *Tamkang Journal of Science and Engineering,* vol. 2, no. 3, pp. 63-173 , 1999.

[102] T. B. Sebasian and B. B. Kimia, "Curves vs Skeltons in Object Recognition," in *Proceedings of International Conference on Image Processing,* Thessaloniki, 7-10 Oct. 2001 .

[103] L. Kotoulas i I. Andreadis, „Image analysis using moments," w *Proceedings of 5th International Conference on Technology and Automation*, Thessaloniki, Greece, 2005.

[104] M. R. Teague, "Image analysis via the general theory of moments," *Journal of the Optical Society of America,* vol. 70, no. 8, pp. 920-930, 1980.

[105] R. Arandjelović and A. Zisserman, "Three things everyone should know to improve object retrieval," in *IEEE Conference on Computer Vision and Pattern Recognition*, Providence, RI, USA, 2012.

[106] K. Mikolajczyk and C. Schmid, "Scale & Affine Invariant Interest Point Detectors," *International Journal of Computer Vision,* pp. 63-86, 2004.

[107] F. Perronnin, J. Sanchez and T. Mensink, "Improving the Fisher Kernel for Large-Scale Image Classification," in *European Conference on Computer Vision, Lecture Notes in Computer Science*, Heraclion, Greece, Sep, 2010.

[108] F. Perronnin and C. Dance, "Fisher Kernels on Visual Vocabularies for Image Categorization," in *Proceeding Computer Vision and Pattern Recognition*, 2007.

[109] J. Krapac and S. Śegvić, "Weakly Supervised Object Localization with Large Fisher Vectors," in *Proceedings of the 10th International Conference on Computer Vision Theory and Applications*, Berlin, 11-14 Mar, 2015.

[110] H. Jegou, M. Douze, C. Schmid and P. Perez, "Aggregating local descriptors into a compact image representation," in *IEEE Conference on Computer Vision and Pattern Recognition*, San Francisco, 13-18 June, 2010.

[111] E. Rosten and T. Drummond, "Fusing points and lines for high performance tracking," in *IEEE International Conference on Computer Vision*, 2005.

[112] E. Rosten i T. Drummond, „Machine learning for high-speed corner detection," w *European Conference on Computer Vision*, 2006.

[113] E. Rublee, V. Rabaud , K. Konolige and G. Bradski, "ORB: an efficient alternative to SIFT or SURF," in *IEEE International Conference on Computer Vision (ICCV)*, Barcelona, Spane, 6-12, Nov, 2011.

[114] M. Brown, R. Szeliski i S. Winder, „Multi-image matching using Multi-Scale Oriented Patches," *Computer Vision and Pattern Recognition,* nr 2, pp. 510-517, 2005.

[115] The Moving Picture Experts Group, "MPEG," [Online]. Available: http://mpeg.chiariglione.org/. [Accessed 2015].

[116] MPEG, "MPEG standards - Full list of standards developed or under development," 20 April 2010. . [Online]. Available: http://mpeg.chiariglione.org/standards.htm.

[117] I. JTC1/SC29/WG11, "CODING OF MOVING PICTURES AND AUDIO MPEG-7". Palma de Mallorca, Spain Patent N6828, Oct. 2004.

[118] M. J. Swain and D. H. Ballard, "Color Indexing," *International Journal of Computer Vision,* vol. 7, no. 1, pp. 11-32, 1991.

[119] V. Castelli i L. D. Bergman, Redaktorzy, Image Databases: Search and Retrieval of Digital Imagery, New York: Wiley, 2002.

[120] J.-J. Chen, C.-R. Su, W. E. L. Grimson, J.-L. Liu and D.-H. Shiue, "Object Segmentation of Database Images by Dual Multiscale Morphological Reconstructions and Retrieval Applications," *IEEE Transactions on Image Processing,* vol. 21, no. 2, pp. 828-843, Feb. 2012.

[121] P. Melin and O. Castillo, Hybrid Intelligent Systems for Pattern Recognition Using Soft Computing. An Evolutionary Approach for Neural Networks and Fuzzy Systems., Berlin: Springer, 2005, p. 272.

[122] J. C. Bezdek, Pattern Recognition with Fuzzy Objective Function Algorithms., New York: Plenum Press, 1981, p. 272.

[123] Y. Cheng , "Mean Shift Mode Seeking, and Clustering," *IEEE TRANSACTIONS on PATTERN ANALYSIS and Machine Intelligence,* vol. 17, no. 8, Aug, 1995.

[124] G. Seber, Multivariate Observations, New York: Wiley, 1984, p. 686.

[125] H. Späth, Cluster analysis algorithms for data reduction and classification of objects, vol. 4, Pensilvania University: E. Horwood, 1980, p. 226.

[126] M. Acharyya and M. K. Kundu, "An adaptive approach to unsupervised texture segmentation using M-Band wavelet transform," *Signal Processing,* no. 81, pp. 1337-1356, 2001.

[127] L. J. Latecki and R. Lakamper, "Application of planar shape comparison to object retrieval in image databases," *Pattern Recognition,* no. 35, pp. 15-29, 2002.

[128] W.-B. Goh and K.-Y. Chan, "A Shape Descriptor for Shapes with Boundary Noise and Texture," in *British Machine Vision Conference*, Norwich, 24 June, 2003.

[129] C. Xu and J. Liu, "2D Shape Matching by Contour Flexibility," *IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE,* vol. 31, no. 1, Jan. 2009.

[130] J. Mutch and D. G. Lowe, "Object class recognition and localization using sparse features with limited receptive fields," *International Journal of Computer Vision (IJCV),* vol. 80, no. 1, pp. 45-57, Oct 2008.

[131] T. Serre, L. Wolf and T. Poggio, "Object Recognition with Features Inspired by Visual Cortex," in *Proceedings on Computer Vision and Pattern Recognition*, Los Alamos, 2005.

[132] Y. Li and L. G. Shapiro, "Object Recognition for Content-Based Image Retrieval," Dagstuhl Seminar, Leibniz, Austria, 2002.

[133] G. Quellec, M. Lamard, G. Cazuguel, B. Cochener and C. Roux, "Fast Wavelet-Based Image Characterization for Highly Adaptive Image Retrieval," *IEEE Transactions on Image Processing,* vol. 21, no. 4, pp. 1613-1623, April 2012.

[134] B. V. Dasarathy, Ed., Nearest neighbor (NN) norms : NN pattern classification techniques, 6th ed., Los Alamitos, Callifornia: IEEE Computer Society Press, 1991.

[135] C. Cortes and V. Vapnik , "Support-Vector Networks," *Machine Learning,* vol. 20, p. 273–297, 1995.

[136] I. Rish, "An empirical study of the Naïve Bayes classifier," in *Proceedings of the IJCAI-2001 Workshop on Empirical Methods in AI,* Brussels, 2001.

[137] G. P. Zhang, "Neural Networks for Classification: A Survey," *IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and reviews,* vol. 30, no. 4, pp. 451-462, Nov 2000.

[138] J. M. Ali, "Content-Based Image Classification and Retrieval: A Rule-Based System Using Rough Sets Framework," in *Artificial Intelligence for Maximizing Content Based Image Retrieval,* Z. Ma, Ed., NY, Springer, 2009, pp. 68-82.

[139] T. Jaworska, "Towards Fuzzy Classificaton in CBIR," in *Information Systems Architecture and Technology.* , Vols. Knowledge Based Approach to the Design, Control and Decision Support, J. Świątek, L. Borzemski, A. Grzech and Z. Wilimowska, Eds., Wrocław, Oficyna Wydawnicza Politechniki Wrocławskiej, 2013, pp. 53-62.

[140] U. M. Fayyad and K. B. Irani, "The attribute selection problem in decision tree generation," in *the 10th National Conference on Artificial Intelligence, AAAI,* 1992.

[141] L. Breiman , J. Friedman , C. J. Stone and R. A. Olshen, Classification and Regression Trees, New York: Chapman and Hall, 1984, p. 368.

[142] J. R. Quinlan, "Induction of Decision Trees," *Machine Learning,* vol. 1, pp. 81-106, 1986.

[143] J. R. Quinlan, C4.5: Programs for Machine Learning, San Mateo: Morgan Kaufmann Publishers, 1993.

[144] H. Schulz, B. Waldvogel, R. Sheikh and S. Behnke, "CURFIL: Random Forests for Image Labeling on GPU," in *Proceedings of the 10th International Conference on Computer Vision Theory and Applications,* Berlin, 11-14 Mar, 2015.

[145] J. Ylioinas, J. Kannala, A. Hadid and . M. Pietikainen, "Learning Local Image Descriptors Using Binary Decision Trees," in *Proceedings of IEEE Winter Conference on Applications of Computer Vision (WACV 2014),*, Steamboat Springs, CO, USA,, 2014.

[146] B. Bouchon-Meunier and C. Marsala, "Fuzzy decision tree and databases," in *Flexible Query Answering Systems,* T. Andreasen, H. Christiansen and H. L. Larsen, Eds., Kluwer Academic Publisher, 1997, pp. 277-288.

[147] J. D. M. Rennie, L. Shih, J. Teevan and D. R. Karge, "Tackling the Poor Assumptions of Naive Bayes Text Classifiers," in *Proceedings of the 20th International Conference on Machine Learning,* Washington, DC, USA, 2003.

[148] N. M. Murty and S. V. Devi, Pattern Recognition: An Algorithmic Approach, vol. z serii Undergraduate Topics in Computer Science, Springer Science & Business Media, 2011, p. 263.

[149] L. Wang, Ed., Support Vector Machines: Theory and Applications, Berlin: Springer, 2005, p. 450.

[150] H. Ishibuchi and Y. Nojima, "Toward Quantitative Definition of Explanation Ability of Fuzzy Rule-Based Classifiers," in *IEEE International Conference on Fuzzy Systems,* Taipei, Taiwan, June 27-39, 2011.

[151] H. Ishibuchi and T. Yamamoto, "Rule weight specification in fuzzy rule-based classification systems," *IEEE Transactions on Fuzzy Systems,* vol. 13, no. 4, pp. 428-435, 2005.

[152] K. Nozaki, H. Ishibuchi and H. Tanaka , "Adaptive fuzzy rule-based classification systems," *IEEE Transactions on Fuzzy Systems,* vol. 13, no. 4, pp. 238-250, 1996.

[153] H. Ishibuchi and Y. Nojima, "Toward Quantitative Definition of Explanation Ability of Fuzzy Rule-Based Classifiers," in *IEEE International Conference on Fuzzy Systems,* Taipei, Taiwan, June 27-39, 2011.

[154] T. Jaworska, "Application of Fuzzy Rule-Based Classifier to CBIR in comparison with other classifiers," in *11th International Conference on Fuzzy Systems and Knowledge Discovery*, Xiamen, China, 2014.

[155] S. K. Candan and W.-S. Li, "On Similarity Measures for Multimedia Database Applications," *Knowledge and Information Systems*, vol. 3, pp. 30-51, 2001.

[156] A. Hamilton-Wright and D. W. Stashuk, "Constructing a Fuzzy Rule Based Classification System Using Pattern Discovery," in *Annual Meeting of the North American Fuzzy Information Processing Society*, 2005.

[157] Y. LeCun, Y. Bengio and G. Hinton, "Deep learning," *Nature*, vol. 521, pp. 436-444, 28 May 2015.

[158] C. Olah, „Conv Nets: A Modular Perspective," blog, July 2014. [Online]. Available: http://colah.github.io/posts/2014-07-Conv-Nets-Modular/.

[159] A. Krizhevsky, I. Sutskeve and G. E. Hinton, "ImageNet Classification with Deep Convolutional Neural Networks," in *Advances in Neural Information Processing Systems*, 2012.

[160] MathWorks Inc., "Deep learning with MATLAB," 2016. [Online]. Available: https://www.mathworks.com/discovery/deep-learning.html.

[161] C.-C. Chang and T.-C. Wu, "An exact match retrieval scheme based upon principal component analysis," *Pattern Recognition Letters*, vol. 16, pp. 465-470, 1995.

[162] D. S. Guru and P. Punitha, "An invariant scheme for exact match retrieval of symbolic images based upon principal component analysis," *Pattern Recognition Letters* , vol. 25, p. 73–86, 2004.

[163] S. Rolewicz, Functional Analysis and Control Theory: Linear Systems, vol. Series: Mathematics and its applications, Warsaw: PWN-Polish Scientific Publishers , 1987.

[164] J. Z. Wang, J. Li and G. Wiederhold, "SIMPLIcity: Semantics-Sensitive Integrated Matching for Picture LIbraries," *IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE,*, vol. 23, no. 9, pp. 947-963, Sep. 2001.

[165] C. Mallows, "A Note on Asymptotic Joint Normality," *The Annals of Mathematical Statistics,* vol. 43, no. 2, pp. 508-515., 1972.

[166] D. Zhou, J. Li and H. Zha, "A new Mallows distance based metric for comparing clusterings," in *Proceedings of the 22nd International Conference on Machine Learning,*, Bonn,m Germany, Aug. 2005.

[167] E. Pękalska and R. P. Duin, The Dissimilarity Representation for Pattern Recognition. Foundations and Applications., 1 ed., Vols. Series in Machine Perception and Artificial Intelligence - Vol. 64, New Jersey, London: World Scientific, 2005, p. 607.

[168] B. Ko and H. Byun, "Integrated Region-Based Image Retrieval Using Region's Spatial Relationships," in *Proceedings of 16th International Conference on Pattern Recognition*, 11-15 Aug. 2002.

[169] C. Beecks, M. S. Uysal and T. Seidl, "A Comparative Study of Similarity Measures for Content-Based Multimedia Retrieval," in *Multimedia and Expo (ICME)*, Suntec City, 19-23 July, 2010.

[170] T. Jaworska, "A Search-Engine Concept Based on Multi-Feature Vectors and Spatial Relationship," in *Flexible Query Answering Systems*, vol. 7022, H. Christiansen, G. De Tré, A. Yazici, S. Zadrożny and H. L. Larsen, Eds., Ghent, Springer, 2011, pp. 137-148.

[171] T. Jaworska, "An Asymmetric Approach to Signature Matching," in *Multimedia and Network Information Systems*, vol. 506, A. Zgrzywa, K. Choraś and A. Siemiński, Eds., Wrocław, Springer, 2016, pp. 27-37.

[172] G. Wu, E. Y. Chang and N. Panda, "Formulating context-dependent similarity functions," in *The 13th annual ACM international conference on Multimedia*, Singapore , Nov., 2005.

[173] A. Natsev and J. R. Smith, "A study of image retrieval by anchoring," in *IEEE International Conference on Multimedia and Expo*, Lausanne, Switzerland , Aug. 2002.

[174] C.-T. Nguyen, X. Wang, J. Liu and Z.-H. Zhou, "Labeling Complicated Objects: Multi-View Multi-Instance Multi-Label Learning," in *28th AAAI Conference on Artificial Intelligence*, Hilton Québec Canada, June, 2014.

[175] H. Mueller, W. Mueller, S. Marchand-Maillet and T. Pun, "A Framework for Benchmarking in CBIR," *Multimedia Tools and Applications,* no. 21, pp. 55-73, 2003.

[176] D. A. Narasimhalu , M. S. Kankanhalli and J. Wu, "Benchmarking Multimedia Databases," *Multimedia Tools and Applications,* vol. 4, no. 3, p. 333–356, May 1997.

[177] J. R. Smith, "Image retrieval evaluation," in *IEEE Workshop on Content-Based Access of Image and Video Libraries (CBAIVL '98)*, Santa Barbara, 1998.

[178] A. Dimai , "Assessment of effectiveness of content-based image retrieval systems," in *3rd International Conference on Visual Information Systems (VISUAL '99)*, Amsterdam, The Netherlands, 1999.

[179] E. L. van den Broek, T. Kok, T. E. Schouten and L. G. Vuurpijl, "Human-Centered Content-Based Image Retrieval," in *Proceedings of XIII Conference on Human Vision and Electronic Imaging*, Feb. 14, 2008.

[180] M. Everingham, A. S. Eslami, L. Van Gool, C. K. I. Williams, J. Winn and A. Zisserman, "The PASCAL Visual Object Classes Challenge: A Retrospective," *International Journal of Computer Vision,* no. 111, p. 98–136, 2015.

[181] Corel comp., "The COREL Database for Content based Image Retrieval".

[182] Z. Yang and C.-C. Jay Kuo, "Learning image similarities and categories from content analysys and relebance feedback," in *Proceedings of the ACM Multimedia Workshops. Multimedia00'*, Los Angeles, CA, USA , Oct 30 - Nov 03, 2000.

[183] the Eastman Kodak Company, [Online]. Available: http://r0k.us/graphics/kodak/.

[184] D.-C. He and A. Safia, "Multiband Texture Database," 2015. [Online]. Available: http://multibandtexture.recherche.usherbrooke.ca/.

[185] D.-C. He and A. Safia, "New Brodatz-based Image Databases for Grayscale Color and Multiband Texture Analysis," *ISRN Machine Vision,* vol. Article ID 876386, pp. 1-14, 2013.

[186] N. Rasiwasia, P. J. Moreno and N. Vasconcelos, "Bridging the Gap: Query by Semantic Example," *IEEE TRANSACTIONS ON MULTIMEDIA,* vol. 9, no. 5, pp. 923-938, Aug 2007.

[187] X. Wang, S. Qiu, K. Liu i X. Tang, „Web Image Re-Ranking Using Query-Specific Semantic Signatures," *IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE,* tom 36, nr 4, pp. 810-823, April 2014.

[188] M. Everingham, L. Van Gool, C. K. I. Williams, A. Zisserman, J. Winn, A. S. Eslami and Y. Aytar , "The PASCAL Visual Object Classes Homepage," 2015. [Online]. Available: http://host.robots.ox.ac.uk/pascal/VOC/index.html.

[189] J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li and L. Fei-Fei, "ImageNet: A Large-Scale Hierarchical Image Database," in *IEEE Conference on Computer Vision and Pattern Recognition*, Miami, USA, June, 2009.

[190] L. Fei-Fei, K. Li, O. Russakovsky, J. Krause, J. Deng and A. Berg, "ImageNet," Stanford Vision Lab, Stanford University, Princeton University, 2014. [Online]. Available: http://www.image-net.org/.

[191] G. Griffin, A. D. Holub and P. Perona, "The Caltech 256," California Institute of Technology, Los Angeles, 2006.

[192] G. Griffin, "Caltech256," 2006. [Online]. Available: http://www.vision.caltech.edu/Image_Datasets/Caltech256/.

[193] J. Philbin, O. Chum and M. a. S. J. a. Z. A. Isard, "Object Retrieval with Large Vocabularies and Fast Spatial Matching," in *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2007.

[194] J. Philbin, R. Arandjelović and A. Zisserman, "The Oxford Buildings Dataset," Department of Engineering Science, University of Oxford, Nov 2012. [Online]. Available: http://www.robots.ox.ac.uk/~vgg/data/oxbuildings/.

[195] J. Philbin, O. Chum and M. a. S. J. a. Z. A. Isard, "Lost in Quantization: Improving Particular Object Retrieval in Large Scale Image Databases," in *IEEE Conference on Computer Vision and Pattern Recognition*, Anchorage, USA, 23-28 June, 2008.

[196] J. Philbin i A. Zisserman, „The Paris Dataset," Visual Geometry Group, Department of Engineering Science, University of Oxford , 2008. [Online]. Available: http://www.robots.ox.ac.uk/~vgg/data/parisbuildings/.

[197] B. C. Becker, "PubFig83 + LFW Dataset," 2015. [Online]. Available: http://www.briancbecker.com/blog/research/pubfig83-lfw-dataset/.

[198] B. C. Becker and E. G. Ortiz, "Evaluating Open-Universe Face Identification on the Web," in *CVPR 2013, Analysis and Modeling of Faces and Gestures Workshop.*, Portland, Oregon, USA, 23-28 June, 2013.

[199] P.-S. P. Chen, "Entity-relationships model – Toward a Unified View of Data," *ACM Transactions on Database Systems,* vol. 1, no. 1, pp. 9-36, 1976.

[200] R. Barker, Entity-Relationship Modelling. Case MethodSM, London, : Addison-Wesley, 1995.

[201] R. Barker and C. Longman , Function and Process Modelling. Case MethodSM, London: Addison-Wesley Pub. Co., 1993.

[202] K. Rodden and K. R. Wood, "How Do People Manage Their Digital Photographs?," in *SIGCHI Conference on Human Factors in Computing Systems*, Ft. Lauderdale, Florida, USA., April 5–10, 2003.

[203] A. W. M. Smeulders, M. Worring, S. Santini, A. Gupta and R. Jain, "Content-Based Image Retrieval at the End of the Early Years," *IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGEN,* vol. 22, no. 12, pp. 1349 - 1380, Dec 2000.

[204] X. Wang, K. Liu and X. Tang, "Query-Specific Visual Semantic Spaces forWeb Image Re-ranking.," in *Computer Vision and Patern Recognition Paper*, 2011.

[205] W. Niblack, M. Flickner, D. Petkovic, P. Yanker, R. Barber, W. Equitz, E. Glasman, C. Faloutsos and G. Taubin, "The QBIC Project: Querying Images by Content Using Colour, Texture and Shape," *SPIE,* vol. 1908, pp. 173-187, 1993.

[206] B. Xiao , X. Gao, D. Tao and X. Li, "Recognition of Sketches in Photos," in *Multimedia Analysis, Processing and Communications*, vol. 346, W. Lin, D. Tao, J. Kacprzyk , Z. Li, E. Izquierdo and H. Wang , Eds., Berlin, Springer-Verlag, 2011, pp. 239-262.

[207] J.-H. Lim and J. S. Jin, "A structured learning framework for content-based image indexing and visual query," *Multimedia Systems,* vol. 10, p. 317–331, 2005.

[208] J. Assfalg, A. Del Bimbo and P. Pala, "Three-Dimensional Interfaces for Querying by Example in Content-Based Image Retrieval," *IEEE Transactions on Visualization and Computer Graphics* , vol. 8, no. 4, pp. 305-318, Oct-Dec 2002.

[209] J. Fauqueur and N. Boujemaa, "Mental image search by boolean composition of region categories," *Multimed Tools and Applications,* vol. 31, p. 95–117, 2006.

[210] T. Jaworska, "Multi-criteria object indexing and graphical user query as an aspect of content-based image retrieval system.," in *Information Systems Architecture and Technology,* L. Borzemski, A. Grzech, J. Świątek and Z. Wilimowska, Eds., Wrocław, Wrocław Technical University Publisher, 2009, pp. 103-112.

[211] . B. Moghaddam, H. Biermann and D. Marg, "Regions-of-Interest and Spatial Layout for Content-Based Image Retrieval," *Multimedia Tools and Applications,* vol. 14, no. 2, pp. 201-210, June 2001.

[212] M. M. Rahman, S. K. Antani and G. R. Thoma, "A query expansion framework in image retrieval domain based on local and global analysis," *Information Processing and Management,* vol. 47, pp. 676-691, 2011.

[213] J. Fauqueur, "Instantaneous mental image search with range queries on multiple region descriptors," Cambridge, UK, Jan, 2005.

[214] Y. Liu, D. Zhang, G. Lu and W.-Y. Ma, "A survey of content-based image retrieval with high-level semantics," *Pattern Recognition,* vol. 40, pp. 262-282, 2007.

[215] J. C. Cubero, N. Marín, J. M. Medina, E. Pons and A. M. Vila, "Fuzzy Object Management in an Object-Relational Framework," in *Proceedings of the 10th International Conference IPMU,* Perugia, Italy, 4-9 July, 2004.

[216] F. Berzal, J. C. Cubero, J. Kacprzyk, N. Marín, A. M. Vila and S. Zadrożny, "A General Framework for Computing with Words in Object-Oriented Programming.," in *International Journal of Uncertainty. Fuzziness and Knowledge-Based Systems.*, vol. 15 (Suppl), Singapore, World Scientific Publishing Company, 2007, pp. 111 131,.

[217] W. Plant and G. Schaefer, "Visualization and Browsing of Image Databases," in *Multimedia Analysis, Processing and Communications,* vol. 346, W. Lin, D. Tao, J. Kacprzyk , Z. Li, E. Izquierdo and H. Wang, Eds., Berlin, Springer, 2011, pp. 3-57.

[218] K. Rodden, „Evaluating similarity-based visualisations as interfaces for image browsing," University of Cambridge, Cambridge, 2002.

[219] K. Rodden, K. R. Wood, W. Basalaj and D. Sinclair, "Evaluating a Visualisation of Image Similarity as a Tool for Image Browsing," in *IEEE Symposium on Information Visualisation,* 1999.

[220] W. Basalaj, "Proximity visualisation of abstract data," University of Cambridge, Cambridge, 2001.

[221] C. Faloutsos and K. Lin, "Fast Map: A Fast Algorithms for Indexing, Data-Mining and Visualization of Traditional and Multimedia Datasets," in *ACM SIGMOD international conference on Management of data* , New York, USA, May, 1995.

[222] L. F. D. Santos, R. L. Dias and M. X. Ribeiro, "Combining Diversity Queries and Visual Mining to Improve Content-Based Image Retrieval Systems: The DiVI Method," in *IEEE International Symposium on Multimedia,* Miami, Dec. 2015.

[223] A. Bursuc and T. Zaharia, "ARTEMIS@ MediaEval 2013: A Content-Based Image Clustering Method for Public Image Repositories," *ACM Multimedia,* pp. 18-19, Oct. 2013.

[224] C. Chen, G. Gagaudakis and P. Rosin, "Similarity-Based Image Browsing," in *Proceedings of the 16th IFIP World Computer Congress, International Conference on Intelligent Information Processing,* Beijing, China, 2000.

[225] T. Kohonen, "The Self_Organizing Map," *Proceedings of IEEE,* vol. 78, no. 9, pp. 1464-1480, Sep. 1990.

[226] A. Csillaghy , H. Hinterberger and A. B. Benz, "Content-Based Image Retrieval in Astronomy," *Information Retrieval Journal,* vol. 3, no. 3, pp. 229-241, 2000.

[227] Y. Rui and T. S. Huang, "Relevance Feedback Techniques in Image Retrieval," in *Principal of Visual Information Retrieval,* M. S. Lew, Ed., London, Springer, 2001, pp. 219-258.

[228] V. Mezaris, I. Kompatsiaris and M. G. Strintzis, "An ontology approach to object-based image retrieval," in *Proceedings of International Conference on Image Processing ICIP 2003.*, 2003.

[229] A. D. Gudewar and L. R. Ragha, "Ontology to Improve CBIR System," *International Journal of Computer Applications,* vol. 52, no. 21, pp. 23-30, 2012.

[230] C. Doulaverakis, E. Nidelkou, A. Gounaris and Y. Kompatsiaris, "A Hybrid Ontology and Content-Based Search Engine For Multimedia Retrieval," in *Workshop Proceedings in Advances in Databases and Information Systems ADBIS '2006,* Thessaloniki, 2006.

[231] O. Allani, N. Mellouli, H. B. Zghal, H. Akdag and H. B. Ghzala, "A Relevant Visual Feature Selection Approach for Image Retrieval," in *Proceedings of the 10th International Conference on Computer Vision Theory and Applications,* Berline, 11-14 Mar, 2015.

[232] O. Russakovsky and L. Fei-Fei, "Attribute Learning in Large-scale Datasets," in *Proceedings of the 12th European Conference of Computer Vision (ECCV), 1st International Workshop on Parts and Attributes.,* Crete, Greece, 2010.

[233] T. Hofmann, "Probabilistic latent semantic analysis," in *Proceedings of the15th Conference on Uncertainty in Artificial Intelligence,* Stockholm, 1999.

[234] D. M. Blei, A. Y. Ng and M. I. Jordan, "Latent Dirichlet Allocation," *Journal of Machine Learning Research,* vol. 3, pp. 993-1022, 2003.

[235] L. Fei-Fei and P. Perona, "A Bayesian Heirarcical Model for Learning Natural Scene Categories," in *Computer Vision & Pattern Recognition CVPR,* 2005.

[236] J. Sivic, B. C. Russell, A. A. Efros, A. Zisserman and W. T. Freeman, "Discovering objects and their location in images," in *Proceedings of Internationa Conference of Computer Vision,* Beijing, 2005.

[237] J. Bautista-Ballester, J. Verges-Llahi and D. Puig, "Using Action Objects Contextual Information for a Multichannel SVM in an Action Recognition Approach based on Bag of VisualWords," in *Proceedings of the 10th International Conference on Computer Vision Theory and Applications,* Berlin, 11-14 Mar, 2015.

[238] T. Kinnunen, J.-K. Kamarainen, L. Lensu and H. Kälviäinen, "Unsupervised object discovery via self-organisation," *Pattern Recognition Letters,* no. 33, p. 2102–2112, Aug 2012.

[239] J. Urban, J. M. Jose and C. J. van Rijsbergen, "An adaptive technique for content-based image retrieval," *Multimedial Tools Applied,* no. 31, pp. 1-28, July 2006.

[240] L. Zhang, L. Wang and W. Lin, "Generalized biased discriminant analysis for content-based image retrieval," *IEEE Transactions on System, Man, Cybernetics, Part B - Cybernetics,* vol. 42, no. 1, pp. 282-290, 2012.

[241] L. Zhang, L. Wang and W. Lin, "Semi-supervised biased maximum margin analysis for interactive image retrieval," *IEEE Transactions on Image Processing,* vol. 21, no. 4, pp. 2294-2308, 2012.

[242] S. T. Roweis and L. K. Saul, "Nonlinear Dimensionality Reduction by Locally Linear Embedding," *Science,* vol. 290, no. 5500, pp. 2323-2326, Dec. 2000.

[243] S.-F. Chang, W. Chen and H. Sundaram, "Semantic Visual Templates: Linking Visual Features to Semantics," in *International Conference on Image Processing, 1998. ICIP 98.,* Chicago, 1998.

[244] Y. Zhuang, X. Liu and Y. Pan, "Apply Semantic Template to Support Content-based Image Retrieval," in *the Proceeding of IS&T and SPIE Storage and Retrieval for Media Databases 2000,* San Jose, California, USA, Jan, 2000.

[245] G. A. Miller, R. Beckwith, C. Fellbaum, D. Gross and K. Miller, "Introduction to WordNet: An On-line Lexical Database," *Communications of the ACM,* vol. 38, no. 11, pp. 39-41 , Nov. 1995.

[246] M. Mucha and P. Sankowski, "Maximum Matchings via Gaussian Elimination," in *Proceedings of the 45th Annual Symposium on Foundations of Computer Science (FOCS'04),* 2004.

[247] Z. Wang , A. C. Bovik, H. R. Sheikh and E. P. Simoncelli, “Image Qualifty Assessment: From Error Visibility to Structural Similarity,” *IEEE Transactions on Image Processing,* vol. 13, no. 4, p. 600–612, April 2004.

[248] E. Candes, L. Demanet, D. Donoho and L. Ying, “Fast Discrete Curvelet Transforms,” 2006.

[249] I. Aizenberg, N. N. Aizenberg and J. P. Vandewalle, Multi-Valued and Universal Binary Neurons, Springer US, Springer Science+Business Media Dordrecht, 2000, p. 276.

[250] T. Yamashita, T. Watasue, Y. Yamauchi and H. Fujiyoshi, “Improving Quality of Training Samples Through Exhaustless Generation and Effective Selection for Deep Convolutional Neural Networks,” in *Proceedings of the 10th International Conference on Computer Vision Theory and Applications*, Berlin, 11-14 Mar, 2015.

[251] F. Jurišić, I. Filković and Z. Kalafatić, “Evaluating the Effects of Convolutional Neural Network Committees,” in *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016)*, Rome, Italy, 27-29 Feb, 2016.

[252] H. H. Aghdam, E. J. Heravi and D. Puig, “Analyzing the Stability of Convolutional Neural Networks against Image Degradation,” in *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016)*, Rome, Italy, 27-29 Feb, 2016.

[253] S. Srinivasulu and P. Sakthivel , “Extracting Spatial Semantics in Association Rules for Weather Forecasting Image,” in *Trendz in Information Sciences & Computing(TISC2010)*, Chennai, 17-19 Dec. 2010.

[254] A. Moumtzidou, V. Epitropou, S. Vrochidis, K. Karatzas, S. Voth, A. Bassoukos, J. Moßgraber, A. Karppinen, J. Kukkone and I. Kompatsiaris, “A model for environmental data extraction from multimedia and its evaluation against various chemical weather forecasting datasets.,” *Ecological Informatics,* no. 23, p. 69–82, Sep. 2014.

[255] K. Choroś, “False and Miss Detections in Temporal Segmentation of TV Sports News Videos - Causes and Remedies,” in *New Research in Multimedia and Internet Systems*, Advances in Intellignet Systems and Computing ed., vol. 314, A. Zgrzywa, . K. Choroś and A. Siemiński, Eds., Wrocław, Springer, 2015, pp. 35-46.

[256] J. Li, „The application of CBIR-based system for the product in electronic retailing,” w *2010 IEEE 11th International Conference on Computer-Aided Industrial Design & Conceptual Design (CAIDCD)*, Yiwy, China, 17-19 Nov. 2010.

[257] G. De Tre, D. Vandermeulen, J. Hermans, P. Claes, J. Nielandt and A. Bronselaer, “Bipolar Comparison of 3D Ear Models,” in *Information Processing and Management of Uncertainty in Knowledge-Based Systems - 15th International Conference - IPMU*, Montpellier, France, 2014.

[258] A. E. Carpenter, “Extracting Rich Information from Images,” in *Cell-Based Assays for High-Throughput Screening*, P. A. Clemons, N. J. Tolliday and B. K. Wagner , Eds., Springer, 2009, pp. 193-211.

[259] M. Mansourvar and M. A. Ismail, “Content-Based Image Retrieval in Medical Systems,” *International Journal of Information Technology,* vol. 20, no. 2, pp. 1-9, 2014.

[260] A. Obero and M. Singh, “Content Based Image Retrieval System for Medical Databases (CBIR-MD) - Lucratively tested on Endoscopy, Dental and Skull Images,” *IJCSI International Journal of Computer Science Issues,* vol. 9, no. Issue 3, No 1, May 2012.

[261] M. S. Chaibou and K. Kalti, “A New Labeled Quadtree-based Distance for Medical Image Retrieval,” in *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016)*, Rome, Italy, 27-29 Feb., 2016.

[262] H.-s. Kim, H.-W. Chang, H. Liu, J. Lee and D. Lee, "BIM: IMAGE MATCHING USING BIOLOGICAL GENE SEQUENCE ALIGNMENT," 2010. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5414214.

[263] A. T. Inc., "image pattern recognition using vector quantization - uszczegółowić". the United States Patent and Trademark Office Patent 7,502,519, 2009.

[264] J. Mallik, A. Samal and S. L. Gardnerb, "A content based image retrieval system for a biological specimen collection," *Computer Vision and Image Understanding,* vol. 114, no. 7, p. 745–757, July 2010.

[265] G. Csurka, J. Ah-Pine and S. Clinchant, "Unsupervised Visual and Textual Information Fusion in CBMIR Using Graph-Based Methods," *ACM Transactions on Information Systems,* vol. 33, no. 2, pp. 9:1--9:31, Feb, 2015.

[266] L. Anselin and S. J. Rey, Eds., Perspectives on Spatial Data Analysis, Berlin: Springer, 2010, p. 290.

[267] C. Hahne, A. Aggoun, S. Haxha, V. Velisavljevic and J. C. J. Fernández, "Light field geometry of a standard plenoptic camera," *Optics Express,* vol. 22, no. 22, pp. 26659-26673, Nov. 2014.

[268] S. Cloix, T. Pun and D. Hasler, "Real-time Scale-invariant Object Recognition from Light Field Imaging," in *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016),* Rome, Italy, 27-29 Feb., 2016.

[269] *IEEE Transactions on Image Processing,* vol. 13, no. 3, p. all, March 1994.

[270] S. Lyu, D. Rockmore i H. Farid, „A digital technique for art authentication," *Proceedings of the National Academy of Sciences of the United States of America,* tom 101, nr 49, p. 17006–17010, 7 Dec. 2004.

[271] M. Aubry, B. C. Russell and J. Sivic, "Painting-to-3D Model Alignment Via Discimanative Visual Elements," *ACM Transactions on Graphics,* vol. 28, no. 4, pp. 1-14, Article No. 106 , Aug. 2009.

[272] J. K. Gilbert, Ed., Visualization in Science Education, Springer Science & Business Media, 2006, p. 346.

[273] E. Alepis and M. Virvou, Object-Orianted User Interfaces fro Personalized Mobile Learning, vol. 64, J. Kacprzyk and J. C. Lakhimi, Eds., Heidelberg: Springer, 2014, p. 129.

[274] G. Ghiani, M. Manca and F. Paternò, "Authoring Context-dependent Cross-device User Interfaces based on Trigger/Action Rules," in *The 14th International Conference on Mobile and Ubiquitous Multimedia,* Linz, Austria, 30 Nov. - 2nd Dec. 2015.

[275] Z. Raisi, F. Mohanna and M. Rezaei, "Applying Content-Based Image Retrieval Techniques to Provide New Services for Tourism Indusry," *International Journal of Advanced Networking and Applications,* vol. 6, no. 2, pp. 2222-2232, Oct. 2014.

[276] W. Premchaiswadi, "An Image Search for Tourist Information Using a Mobile Phone," *WSEAS Transactions on Information Science and Applications,* vol. 4, no. 7, pp. 532-541, Apr 2010.

[277] M. Markkula and E. Sormunen, "Searching for Photos - Journalists' Practices in Pictorial IR," in *Electronic Workshops in Computing – Challenge of Image Retrieval,* Newcastle, UK,, Feb. 1998.

[278] D. Gurari, S. D. Jain, M. Betke and K. Grauman, "Pull the Plug? Predicting If Computers or Humans Should Segment Images," in *the IEEE Conference on Computer Vision and Pattern Recognition (CVPR),* Las Vegas, June, 2016.

[279] R. Datta, T. Joshi, J. Li and J. Z. Wang, "Image Retrieval: Ideas, Influences, and Trends of the New Age," *ACM Computing Surveys,* vol. 40, no. 2, pp. 5:1-5:60, Apr. 2008.

[280] B. B. Mandelbrot and J. W. Van Ness, “Fractional Brownian Motions, Fractional Noises and Applications,” *SIAM Review,* vol. 10, no. 4, pp. 422-437, October 1968.

[281] A. Kundu and J.-L. Chen, “Texture classification using QMF bank-based subband decomposition,” *CVGIP: Graphical Models and Image Processing,* vol. 54, no. 5, p. 369–384, 1992.

[282] C. Xu and J. L. Prince, “Snakes, Shapes, and Gradient Vector Flow,” *IEEE TRANSACTIONS ON IMAGE PROCESSING,* vol. 7, no. 3, pp. 359-369, March 1998.

[283] “Fast Wavelet-Based Image Characterization for Highly Adaptive Image Retrieval,” *IEEE Transactions on Image Processing,* 2012.

[284] D. Eads, D. Helmbold and E. Rosten, “Boosting in Location Space,” Santa Cruz, 2013.

[285] C. Faloutsos, R. Barber, M. Flickner, J. Hafner, W. Niblack and D. Petkovic, “Efficient and Effective Querying by Image Content.,” *Journal of Intelligent Information Systems,* vol. 3, pp. 231-262, 1994.

[286] M. Koyuncu and B. Cetinkaya, “A Component-Based Object Detection Method Extended with a Fuzzy Inference Engine,” in *Proceedings of the International Conference on Fuzzy Systems Fuzz-IEEE2015,* Istambul, 2015.

[287] J. Philbin, O. Chum and M. a. S. J. a. Z. A. Isard, “Object Retrieval with Large Vocabularies and Fast Spatial Matching,” in *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition,* 2007.

[288] K. Chen, “Deep and Modular Neural Networks,” in *Handbook Computational Intelligence,* 1 ed., J. Kacprzyk and W. Pedrycz, Eds., Berlin, Springer, 2015, pp. 473-494.

[289] A. Huneiti and M. Daoud, “Content-Based Image Retrieval Using SOM and DWT,” *Journal of Software Engineering and Applications,* no. 8, pp. 51-61, Feb 2015.

[290] L. Deng and D. Yu, “Deep Learning Methods and Applications,” in *Foundations and Trends in Signal Processing,* Vols. 7, nos. 3–4, Now the essence of knowledge, 2014, p. 197–387.

[291] J. Bautista-Ballester, J. Verges-Llahi and D. Puig, “Using Action Objects Contextual Information for a Multichannel SVM in an Action Recognition Approach based on Bag of VisualWords,” in *Proceedings of the 10th International Conference on Computer Vision Theory and Applications,* Berlin, 11-14 Mar, 2015.

[292] O. Allani, N. Mellouli, H. B. Zghal, H. Akdag and H. B. Ghzala, “A Relevant Visual Feature Selection Approach for Image Retrieval,” in *VISAPP 2015 - International Conference on Computer Vision Theory and Applications,* Berlin, 2015.

[293] R. K. Srihari , “Automatic indexing and content-based retrieval of captioned images,” *IEEE Computer,* pp. 49 - 56, Sep. 1995.

[294] Y. Liu, D. Zhang, G. Lu and W.-Y. Ma, “A survey of content-based image retrieval with high-level semantics,” *Pattern Recognition,* vol. 40, pp. 262-282, 2007.

[295] S. K. Pal and P. Mitra, Pattern Recognition Algorithms for Data Mining. scalability, Knowledge Discovery and Soft Granular Computing., London, New York: Chapman and Hall CRC Press Company, 2004, p. 244.

[296] C. Beecks, M. S. Uysal and T. Seidl, “Signature Quadratic Form Distances fer Content-Based Similarity,” in *ACM Multimedia,* Beijing, China, Oct. 19-24, 2009.

[297] H. E. Hurst, „Long-term storage capacity of reservoirs,” *Transactions of the American Society of Civil Engineers,* pp. 770-808, 1951.

[298] N. Sebe and M. S. Lew, “Texture Features for Content-Based Retrieval,” in *Principles of Visual Information Retrieval,* M. S. Lew, Ed., Springer Science & Business Media, 2013, pp. 50-81.

[299] I. Rish, “An empirical study of the naive Bayes classifier,” in *IJCAI-2001 workshop on Empirical Methods in AI,* 2001.

[300] R. Datta, J. Li and J. Z. Wang, "Content-Based Image Retrieval - Approaches and Trends of the New Age," in *Multimedia Information Retrieval (MIR '05)*, Singapour, 2005.

[301] T. Jaworska, "The Concept of a Multi-Step Search-Engine for the Content-Based Image Retrieval Systems," in *Information Systems Architecture and Technology. Web Information Systems Engineering, Knowledge Discovery and Hybrid Computing*, Wrocław, 2011.

[302] Z. Wang , A. C. Bovik, H. R. Sheikh and E. P. Simoncelli, "Image Qualifty Assessment: From Error Visibility to Structural Similarity," *IEEE Transactions on Image Processing*, vol. 13, no. 4, p. 600–612, April 2004.

Index

List of Figures