率, 主要困难是需要根据经验找到适当的颜色空间和决策规则. 与传统的检测方法相比, 机器学习会较少地依赖先验知识, 分类精确度较高, 但机器学习的研究难点是结构复杂度和高训练成本.

从这些技术现状可以看出, 基于像素的肤色检测目前仍然存在如下主要问题.

(1) 检测方法与颜色空间的选择. 基于像素的检测方法大部分都要确认颜色空间的选择, 颜色空间的选择与数据库图像若干因素相关, 例如照明、成像条件、噪声、图像尺寸及清晰度等. 这些图像可以改变特定颜色空间的检测结果. 为了找到检测方法的最优颜色空间, 应考虑可能影响性能的所有因素.

(2) 检测任务的数据样本与评价标准的建设. 目前, 虽然文献中有许多肤色模型, 但是如何测量模型的实用性, 以及该模型的有效性范围都存在限制. 通常, 模型的性能取决于许多因素, 例如使用的颜色空间、分布的形状、使用的参数、数据的性质、训练样本的大小、图像特征、噪声数据等. 为了定量客观地比较各种肤色检测技术, 需要加强公用肤色数据库的建设, 统一方法评测标准和规范.

(3) 光照、种族、成像设备和复杂背景等肤色挑战问题的解决与继续优化. 虽然许多检测方法考虑到肤色检测挑战带来的影响, 并试图解决这些不利因素. 但都是针对单一因素的解决, 需要改进算法解决多因素影响下的肤色挑战任务.

针对这些问题, 本文归纳了未来基于像素的肤色检测方法的一些发展趋势, 供读者参考.

(1) 结合空间信息的肤色检测. 肤色特征通常单独使用效果不佳, 结合与空间分布有关的信息, 如纹理、形状和梯度等, 可以有效提高肤色检测性能.

(2) 自适应动态肤色模型的建立. 手动建立的肤色模型在不同的检测条件下会有局限性. 建立动态肤色模型包括动态直方图、高斯分布自适应等肤色分布动态更新方法, 在提高检测性的同时更好地适应于不同的检测环境.

(3) 预处理与后处理步骤的加强. 预处理对于排除复杂背景以及减少光照影响至关重要, 可以通过照明补偿技术增强检测方法对光照的可控程度. 通过形态学后处理增强肤色分割的效果.

(4) 结合不同检测算法进行肤色检测与识别. 每种肤色检测算法都有各自的优缺点, 可以通过不同方法的融合实现分类精度高、易操作和降低复杂度及训练成本, 同时提高肤色检测准确度的检测效果.

6 总结

基于像素的肤色检测方法是肤色检测技术采用的基础方法. 其中, 基于统计与基于阈值的肤色检测方法着重于参数与聚类模型的建立, 易操作; 基于机器学习的方法通过训练数据集找到肤色区域, 检测精度高. 它们的局限性都在于不能适应动态实时检测任务, 以及开放式数据库的检测. 本文探讨了基于像素的肤色检测方法相关理论与研究, 归纳了现存研究问题与发展趋势. 最终目的是为肤色检测的方法及其应用的研究提供参考.

参考文献

1 Zaqout I, Zainuddin R, Baba S. Human face detection in color images. Advances in Complex Systems, 2004, 7(3): 369–383. [doi: 10.1142/S021952590400024X]

2 Li XH, Lam KM, Shen LS, *et al*. Face detection using simplified Gabor features and hierarchical regions in a cascade of classifiers. Pattern Recognition Letters, 2009, 30(8): 717–728. [doi: 10.1016/j.patrec.2009.03.006]

3 Verma A, Raj SA, Midya A, *et al*. Face detection using skin color modeling and geometric feature. Proceedings of 2014 International Conference on Informatics, Electronics & Vision. Dhaka, Bangladesh. 2014. 1–6.

4 Pujol FA, Pujol M, Jimeno-Morenilla A, *et al*. Face detection based on skin color segmentation using fuzzy entropy. Entropy, 2017, 19(1): 26. [doi: 10.3390/e19010026]

5 Kovac J, Peer P, Solina F. Human skin color clustering for face detection. Proceedings of the IEEE Region 8 EUROCON: Computer as a Tool. Ljubljana, Slovenia. 2003. 144–148.

6 Hsu RL, Abdel-Mottaleb M, Jain AK. Face detection in color images. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2002, 24(5): 696–706. [doi: 10.1109/34.1000242]

7 Gejguš P, Šperka M. Face tracking in color video sequences. Proceedings of the 19th Spring Conference on Computer Graphics. Budmerice, Slovakia. 2003. 245–249.

8 Kim MH, Park JB, Joo YH. New fuzzy skin model for face detection. Proceedings of the 18th Australasian Joint Conference on Artificial Intelligence. Sydney, Australia. 2005. 557–566.

9 Barbu T. Pedestrian detection and tracking using temporal differencing and HOG features. Computers & Electrical Engineering, 2014, 40(4): 1072–1079. [doi: 10.1016/j.compeleceng.2013.12.004]

10 Chaichulee S, Villarroel M, Jorge J, *et al*. Multi-task convolutional neural network for patient detection and skin segmentation in continuous non-contact vital sign monitoring. Proceedings of the 12th IEEE International Conference on Automatic Face & Gesture Recognition. Washington, DC, USA. 2017. 266–272. [doi: 10.1109/FG.2017.41]

11 Perez M, Avila S, Moreira D, *et al*. Video pornography detection through deep learning techniques and motion information. Neurocomputing, 2017, 230: 279–293. [doi: 10.1016/j.neucom.2016.12.017]

12 Carlsson A, Eriksson A, Isik M. Automatic detection of images containing nudity: Image detection using artificial neural networks and statistical methods[Master's thesis]. New Zealand: Chalmers Tekniska Högskola, Chalmers University of Technology, 2008.

13 Duan L, Cui G, Gao W, *et al*. Adult image detection method base-on skin color model and support vector machine. Proceedings of the 5th Asian Conference on Computer Vision. Melbourne, Australia. 2002. 797–800.

14 Rowley HA, Jing YS, Baluja S. Large scale image-based adult-content filtering. Proceedings of the First International Conference on Computer Vision Theory and Applications. Setúbal, Portugal. 2006.

15 Lee JS, Kuo YM, Chung PC, *et al*. Naked image detection based on adaptive and extensible skin color model. Pattern Recognition, 2007, 40(8): 2261–2270. [doi: 10.1016/j.patcog.2006.11.016]

16 Sevimli H, Esen E, Ateş TK, *et al*. Adult image content classification using global features and skin region detection. In: Gelenbe E, Lent R, Sakellari G, et al, eds. Computer and Information Sciences. Dordrecht: Springer, 2011. 253–258.

17 Chin TY. Fuzzy skin detection [Master's thesis]. Malaysia: University Teknologi Malaysia, 2008.

18 Albiol A, Torres L, Bouman CA, *et al*. A simple and efficient face detection algorithm for video database applications. Proceedings 2000 International Conference on Image Processing. Vancouver, Canada. 2000. 239–242. [doi: 10.1109/ICIP.2000.899286]

19 Ma WY, Zhang HJ. Content-based image indexing and retrieval. In: Furht B, ed. Handbook of Multimedia Computing. London: CPC Press, 1998. 227.

20 Rasim A, Alexander T. Hand detection based on skin color segmentation and classification of image local features. TEM Journal, 2013, 2(2): 150–155.

21 Habili N, Lim CC, Moini A. Segmentation of the face and hands in sign language video sequences using color and motion cues. IEEE Transactions on Circuits and Systems for Video Technology, 2004, 14(8): 1086–1097. [doi: 10.1109/TCSVT.2004.831970]

22 de Ruijsscher BGC. FPGA based accelerator for real-time skin segmentation [Master's thesis]. Mekelweg: Delft University of Technology, 2006.

23 Bretzner L, Laptev I, Lindeberg T. Hand gesture recognition using multi-scale colour features, hierarchical models and particle filtering. Proceedings of fifth IEEE International Conference on Automatic Face Gesture Recognition. Washington, DC, USA. 2002. 423–428. [doi: 10.1109/AFGR.2002.1004190]

24 Chen FS, Fu CM, Huang CL. Hand gesture recognition using a real-time tracking method and hidden Markov models. Image and Vision Computing, 2003, 21(8): 745–758. [doi: 10.1016/S0262-8856(03)00070-2]

25 Jalab HA, Omer HK. Human computer interface using hand gesture recognition based on neural network. Proceedings of the 2015 5th National Symposium on Information Technology: Towards New Smart World. Riyadh, Saudi Arabia. 2015. 1–6.

26 Rautaray SS, Agrawal A. Vision based hand gesture recognition for human computer interaction: A survey. Artificial Intelligence Review, 2015, 43(1): 1–54. [doi: 10.1007/s10462-012-9356-9]

27 Schaefer G, Tait R, Zhu SY. Overlay of thermal and visual medical images using skin detection and image registration. Proceedings of International Conference of the IEEE Engineering in Medicine and Biology Society. New York, NY, USA. 2006. 965–967.

28 Devi MS, Bajaj PR. Driver fatigue detection based on eye tracking. Proceedings of the 2008 First International Conference on Emerging Trends in Engineering and Technology. Nagpur, India. 2008. 649–652.

29 Chai D, Phung SL, Bouzerdoum A. Skin color detection for face localization in human-machine communications. Proceedings of the Sixth International Symposium on Signal Processing and its Applications. Kuala Lumpur, Malaysia. 2001. 343–346.

30 Jaimes A, Sebe N. Multimodal human-computer interaction: A survey. Computer Vision and Image Understanding, 2007,

108(1–2): 116–134. [doi: 10.1016/j.cviu.2006.10.019]
31 陈锻生, 刘政凯. 肤色检测技术综述. 计算机学报, 2006, 29(2): 194–207. [doi: 10.3321/j.issn:0254-4164.2006.02.002]
32 Kawulok M, Nalepa J, Kawulok J. Skin detection and segmentation in color images. In: Celebi ME, Smolka B, eds. Advances in Low-Level Color Image Processing. Dordrecht: Springer, 2014. 329–366.
33 Jones MJ, Rehg JM. Statistical color models with application to skin detection. International Journal of Computer Vision, 2002, 46(1): 81–96. [doi: 10.1023/A:1013200319198]
34 Nanni L, Lumini A, Dominio F, *et al*. Effective and precise face detection based on color and depth data. Applied Computing and Informatics, 2014, 10(1–2): 1–13. [doi: 10.1016/j.aci.2014.04.001]
35 Ibraheem NA, Khan RZ. Multiple histogram technique for robust skin color based segmentation. American Journal of Engineering Research (AJER), 2013, 2(5): 50–54.
36 Brand J, Mason JS. A comparative assessment of three approaches to pixel-level human skin-detection. Proceedings 15th International Conference on Pattern Recognition. Barcelona, Spain. 2000. 1056–1059.
37 Brown DA, Craw I, Lewthwaite J. A som based approach to skin detection with application in real time systems. Proceedings of the British Machine Vision Conference. Manchester, UK. 2001. 491–500.
38 Yin H, Allinson NM. Self-organizing mixture networks for probability density estimation. IEEE Transactions on Neural Networks, 2001, 12(2): 405–411. [doi: 10.1109/72.914534]
39 Zhu SP, Zhang N. Face detection based on skin color model and geometry features. Proceedings of International Conference on Industrial Control and Electronics Engineering. Xi'an, China. 2012. 991–994.
40 Subban R, Mishra R. Human skin segmentation in color images using gaussian color model. In: Thampi SM, Abraham A, Pal SK, et al, eds. Recent Advances in Intelligent Informatics. Cham: Springer, 2014. 13–21.
41 Montenegro J, Gómez W, Sánchez-Orellana P. A comparative study of color spaces in skin-based face segmentation. Proceedings of the 10th International Conference on Electrical Engineering, Computing Science and Automatic Control. Mexico City, Mexico. 2013. 313–317.
42 Yang MH, Ahuja N. Gaussian mixture model for human skin color and its applications in image and video databases. Proceedings of the SPIE 3656, Storage and Retrieval for Image and Video Databases VII. San Jose: SPIE, 1999. 458–466. [doi: 10.1117/12.333865]
43 Zhu QS, Xie YQ, Gu J, *et al*. A new video object segmentation algorithm by fusion of spatio-temporal information based on GMM learning. In: Lee G, ed. Advances in Automation and Robotics, Vol. 2. Berlin, Heidelberg: Springer, 2011. 641–650.
44 Hossain F, Shamsi M, Alsharif MR, *et al*. Automatic facial skin detection using Gaussian mixture model under varying illumination. International Journal of Innovative Computing, Information and Control, 2012, 8(2): 1135–1144.
45 Caetano TS, Olabarriaga SD, Barone DAC. Do mixture models in chromaticity space improve skin detection? Pattern Recognition, 2003, 36(12): 3019–3021. [doi: 10.1016/S0031-3203(03)00116-X]
46 Lee JY, Yoo SI. An elliptical boundary model for skin color detection. Proceedings of the 2002 International Conference on Imaging Science, Systems, and Technology. Las Vegas, NV, USA. 2002.
47 Naji SN, Jalab HA, Kareem SA. A survey on skin detection in colored images. Artificial Intelligence Review, 2019, 52(2): 1041–1087. [doi: 10.1007/s10462-018-9664-9]
48 Xu D, Chen YL, Wu XY, *et al*. Integrated approach of skin-color detection and depth information for hand and face localization. Proceedings of IEEE International Conference on Robotics and Biomimetics. Karon Beach, Thailand . 2011. 952–956.
49 Tan WJ, Dai GY, Su H, *et al*. Gesture segmentation based on YCb'Cr' color space ellipse fitting skin color modeling. Proceedings of the 2012 24th Chinese Control and Decision Conference. Taiyuan, China. 2012. 1905–1908.
50 Li W, Yang QH, He XB. Face detection algorithm based on double ellipse skin model. Proceedings of the 2011 IEEE 2nd International Conference on Software Engineering and Service Science. Beijing, China. 2011. 335–339.
51 Vezhnevets V, Sazonov V, Andreeva A. A survey on pixel-based skin color detection techniques. In Proceedings of Graphicon-2003. Moscow, Russia. 2003. 85–92.
52 Shaik KB, Ganesan P, Kalist V, *et al*. Comparative study of skin color detection and segmentation in HSV and YCbCr color space. Procedia Computer Science, 2015, 57: 41–48. [doi: 10.1016/j.procs.2015.07.362]
53 Gomez G, Morales EF. Automatic feature construction and a simple rule induction algorithm for skin detection. Proceedings of the ICML Workshop on Machine Learning in Computer Vision. Sydney, Australia. 2002. 31–38.
54 Sagheer A, Aly S. An effective face detection algorithm

based on skin color information. Proceedings of 2012 Eighth International Conference on Signal Image Technology and Internet Based Systems. Naples, Italy. 2012. 90–96. [doi: 10.1109/SITIS.2012.25]

55 Yang GZ, Huang TS. Human face detection in a complex background. Pattern Recognition, 1994, 27(1): 53–63. [doi: 10.1016/0031-3203(94)90017-5]

56 Zahir NB, Samad B, Mustafa M. Initial experimental results of real-time variant pose face detection and tracking system. Proceedings of 2013 IEEE International Conference on Signal and Image Processing Applications. Melaka, Malaysia. 2013. 264–268.

57 Pitas I, Sobottka K. A novel method for automatic face segmentation, facial feature extraction and tracking. Signal Processing: Image Communication, 1998, 12(3): 263–281. [doi: 10.1016/S0923-5965(97)00042-8]

58 Garcia C, Tziritas G. Face detection using quantized skin color regions merging and wavelet packet analysis. IEEE Transactions on Multimedia, 1999, 1(3): 264–277. [doi: 10.1109/6046.784465]

59 Fooprateepsiri R, Kurutach W. A general framework for face reconstruction using single still image based on 2D-to-3D transformation kernel. Forensic Science International, 2014, 236: 117–126. [doi: 10.1016/j.forsciint.2013.12.020]

60 Muralindran M, Nadarajan M, Porle RR, *et al*. A LabVIEW design for frontal and non-frontal human face detection system in complex background. Applied Mechanics and Materials, 2014, 490–491: 1259–1266. [doi: 10.4028/www.scientific.net/AMM.490-491.1259]

61 Xiang FH, Suandi SA. Fusion of multi color space for human skin region segmentation. International Journal of Information and Electronics Engineering, 2013, 3(2): 172–174.

62 Deng L, Yu D. Deep learning: Methods and applications. Foundations and Trends® in Signal Processing, 2014, 7(3–4): 197–387. [doi: 10.1561/2000000039]

63 Kim Y, Hwang I, Cho NI. A new convolutional network-in-network structure and its applications in skin detection, semantic segmentation, and artifact reduction. arXiv: 1701.06190, 2017.

64 Kim Y, Hwang I, Cho NI. Convolutional neural networks and training strategies for skin detection. Proceedings of IEEE International Conference on Image Processing. Beijing, China. 2017. 3919–3923. [doi: 10.1109/ICIP.2017.8297017]

65 Zuo HQ, Fan H, Blasch E, *et al*. Combining convolutional and recurrent neural networks for human skin detection. IEEE Signal Processing Letters, 2017, 24(3): 289–293. [doi: 10.1109/LSP.2017.2654803]

66 Yasar A, Saritas I. Managing intellectual capital and innovation for sustainable and inclusive society: Managing intellectual capital and innovation. Proceedings of the MakeLearn and TIIM Joint International Conference. 2015. 2021–2027.

67 Vicentini RE, Lotufo ADP. Skin detection in digital images with artificial neural networks. Proceedings of Argentine Conference on Automatic Control. Buenos Aires, Argentina. 2018. 1–6. [doi: 10.23919/AADECA.2018.8577440]

68 Al-Mohair HK, Saleh JM, Suandi SA. Hybrid human skin detection using neural network and k-means clustering technique. Applied Soft Computing, 2015, 33: 337–347. [doi: 10.1016/j.asoc.2015.04.046]