A literature survey on eye corner detection techniques in real-life scenarios*

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Abstract. Accurate iris movement detection and tracking is an important and widely used step in many Human-computer interactive applications. Among the eye features, eye corners are considered as stable and reliable reference points to measure the relative iris motion. In real time scenarios, the presence of spectacles prohibit the current state-of-the-art methods to yield accurate detection as the appearance of eye corners changes considerably due to the glare and occlusion caused by them. We term this problem as the Spectacle problem. In this paper we review the available single and multiple image based spectacle problem removal techniques and highlight the pros and cons of the approaches. For this state-of-the-art report, we investigated research papers, patents and thesis presenting the basic definitions, terminologies and new directions for future researches.

Keywords: Eye corners · detection · spectacle problem · specular reflection · glare · occlusion.

1 Introduction

Eyes are one of the most important human facial features. They provide information about a person's identity, intentions and attention levels [44]. Detection, localization, and recognition of eye features is an important step in face detection, Biometric, Human-computer interaction (HCI) and many other diverse applications. Of all the applications, iris movement estimation is a very challenging task as it involves in continuous tracking of eye features. Many algorithms employ projective geometric parameters like the distance between the camera and the subject to estimate the eye position coordinates. However, these measurements will be erroneous when the subject is free to move his/her head. Hence, a relative measurement of pupil position with respect to other fixed reference point(s) may be appropriate to alleviate the problem [4]. Among the eye features, eye corners have the advantage of being robust to various facial expressions, gaze direction and eye status [4,7,10,21,43,44,54,56]. Because of these advantages, localization of eye corners is of great importance as they offer robust reference points.

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1.1 Eye corner detection

Compared to a large amount of iris detection methods, methods related to eye corner detection are limited [4, 49, 54]. One of the prime reason being lack of proper semantic definition of eye corners. Generally, eye corners near to the nose are called the inner eye corners, and the eye corners towards the ears are called the outer eye corners. In literature there are three semantic definitions of eye corners: (a) The intersection between the upper and lower eyelids [1, 7, 10, 13, 16, 41, 49, 54–56]; (b) Eye corner is classified as a pit under image topography perspective [4]; (c) The end of the sclera is labeled as the eye corner [34, 43]. Based on these definitions, various eye corner detection algorithms are available in the literature, which can be broadly classified into three categories namely: Shape based, Feature based, and Sample based models.

Shape based eye corner detections Shape-based models [16,21,34,43,54,59] explores the geometrical shape details between eyes and other facial features in the human face context. Some algorithms assume an eye template consisting of simple geometric primitives and energy function for feature detection. Though shape based model detects eye corners reliably, they suffer from the following lacunas:

- The efficacy of the detection is mainly influenced by the formulation of the template.
- As the template is predetermined, it may not be able to handle real-time scenarios like head pose change.
- The execution time depends on how close the template is initiated to the eye corners. Therefore these approaches may not yield real-time results.

Feature based eye corner detections Feature based methods explore pertinent eye properties like local structure and image intensities to identify the eye corners [35]. No pre-determination and pre-processing of templates is required in these methods. These methods are easy to implement and can be used in real-time operations. In literature, there are two types of feature based corner detection schemes: edge-based and corner detection based. Generally, the edge-based corner detection methods like [52, 56] are more reliable than the corner-based methods [4, 62]. The main challenge for general purpose corner detectors is the fact that image characteristics of eye corners can largely vary between subjects [48, 49]. As a result, reliable detection might be possible only under good imaging conditions.

Sample based eye corner detections Sample based eye corner detection methods [8, 19, 49, 60] try to extract useful visual features from photometric appearance, based on which eye model is learnt from a large set of training images. With the advent of appearance based approaches, many traditional approaches have been replaced by deep-learning methods like Convolutional Neural Networks (CNN). The major advantage of CNN based approaches is it's precision while the limitation is that the efficiency of the methods totally depends on the representative variability of eye appearance in the training data. Due to the usage of large-datasets for training—which involves high performance computing analysis—the brevity and ease of administration is quite questionable.

1.2 Summary

No matter what the approach is, accurate detection and localization of eye features in an unconstrained environment is an ever challenging task due to the high degree of eye's appearance variability. This variability is caused either by intrinsic dynamic features of the eyes or by external factors like spectacles, hair and ambient environment changes. An extensive literature review on this application lead to the identification of several platform specific factors that influence eye feature detection and accuracy. Here, we mention few of the factors that have significant influence on the detection of eye features: Eyebrows [11, 17, 18, 36]; Eyelids [34]; Hair [47]; Head rotation and Pose [35, 44, 63]; Imaging condition and quality [4,9,11,35,41,44,47,51,54]; Semiclosed eyes [7,26,35,48,49]; Spectacles [5,7,8,11,17,22,26,29,30,32,34,36,47–51,53,55,58,60,63]; Squinted eyes [13]; Wrinkles, dark circles, swells, and cosmetics [54, 56].

Of the challenges mentioned above, two standout the most: Spectacles and illumination. [1, 4, 13, 34, 41, 54, 59] circumambulate these challenges by working on facial images without spectacles only. Among [5, 7, 8, 48, 49, 55, 60, 63] - which dealt with spectacle images, papers related to eye corner detection are [49, 55] only. We term the challenges that arise from the usage of spectacles as the spectacle problem [22].

2 Spectacle problem

Though spectacles occupy fewer area in-terms of number of pixels, it has a huge impact on face feature detection as well as tracking algorithms. Two problems occur when the user wears spectacles (see Fig.1). They are:

- Occlusion: Occlusion is the phenomena in which eye features are obstructed by the spectacle frame. Depending upon the comfort, nature, and size of spectacle frame used - most or partial amount of eye feature information may be lost [5, 6, 12, 17, 22, 29].
- Illumination changes: Glare and secondary reflections occur due to the variation in illumination projected on to the human subjects. These variations result in an apparent change on the reflectance properties of the spectacles - leading to a visual variation of the eye features [12, 17, 22, 32, 36, 58].

All the spectacle problem elements individually or cumulatively can vary or obstruct the appearance of the eye features. These factors pose great challenges to the existing eye corner detection strategies. However, little research has been done addressing these issues [11]. One of the major reason being that most of the

(a) (b) (c) (d)

Fig. 1: Sample images from CASIA NIR-VIS 2.0 database [27] illustrating the Spectacle problem. (a),(b) Glare; (c) Occlusion; (d) Secondary reflection

available databases have been collected under well controlled laboratory conditions with normal lighting, neutral expression and high image quality [44]. Such conditions generally do not represent the real-time challenges like the spectacle problems.

3 Datasets

TABLE 1 provides a brief overview of the most used databases in the research field of eye feature detection. This review helps the researchers to choose an appropriate database for their specific research.

Table 1: Real-life scenario databases and their variabilities considered.

Name of the database	**Variation in**				
	Illumination	**Pose**	**Expression**	**Accessories**	**Session**
MIT database [2]					
ORL database [39]	✓	✓	✓	✓	
AR face database [31]					
CurtinFaces dataset [25]					
FEI face database [46]					
COFW [5]		✓	✓	✓	
300 faces in-the-wild [38]					
XM2VTSDB [33]				✓	✓
KFDB [15]	✓	✓	✓	✓	
LWIR imagery [42]	✓		✓	✓	
CASIA NIR-VIS 2.0 database [27]					✓
YALE database [3]	✓		✓	✓	
CASIAWebFace [57]				✓	
LFW [14]	✓	✓	✓	✓	
CAS-PEAL [12]	✓	✓	✓	✓	
FERET database [37]	✓	✓		✓	✓
Indian database [23]	✓	✓	✓	✓	✓

3.1 Summary of database review

- **Illumination**: [42] provides thermal facial imagery, whereas [27] provides facial images captured in NIR illumination. NIR and thermal imaging conditions do not mimic real-time visible conditions. [2, 25, 31, 46, 57] databases are created in visible illumination conditions, but the variation levels are limited. Among the remaining databases, [23, 37] images are captured at low, medium and high illumination conditions of an office environment.
- **Accessories (here spectacles)**: Structural differences in glasses can change the appearance of an individual. Spectacles used in [12] have almost identical shapes, sizes and colors. Therefore, the variation that the accessories bring is not prominent. [23] database have considered the usage of various spectacle frames: Full-rim, Half-rim, and Rim-less - resulting in a larger accessory variation.
- **Ground-truth**: Most of the available databases focus on face detection and recognition. So, the ground-truth information of the eye feature information is hardly found [43]. Also in case of spectacle problem removal algorithms, we need to have pairs of corresponding face images with and without eyeglasses for verifying the seamlessness of the spectacle removal algorithm outputs. Such ground-truth images along with spectacle problem free image and eye corner location details is provided in [23, 29, 51].
- **Database size**: Using private large-scale training datasets, several sample-based algorithms achieve huge success in terms of adaptability and performance. While there are many open source implementations of the algorithms, none of the large-scale face dataset with spectacles is publicly available. [37] considered many variation factors but the quantity of images is very less when compared to [23].

4 Spectacle problem removal: Previous approaches

Due to the unpredictability caused by occlusion, glare and secondary reflection formations, the spectacle removal problem is quite challenging than the detection application [44]. Depending upon the number of input images used to rectify the spectacle problem, the methods can be classified as: Single image based and Multiple image based approaches.

5 Single image approach

One of the most commonly used single image based approach is the image inpainting based approach [28, 45]. Image inpainting techniques are more suitable for texture synthesis applications only and tend to fail in generating a seamless output image in case of facial images [58]. [40] proposed an anti-glare algorithm, in which they assumed that the reflection occurs proportionately on both the eyes. In real-time scenarios, this reflection assumption does not hold good and therefore limits the usability of the algorithm to synthetic images only. In [24] approach, a user has to physically mark the regions in which there are traces of reflection. This approach is more efficient in terms of output results but, the effort and precision of the user will influence the algorithm. [17] proposed a phase congruency based approach, but the algorithms efficiency degrades when the user wear a full-rim spectacle-frame (see Fig. 2).

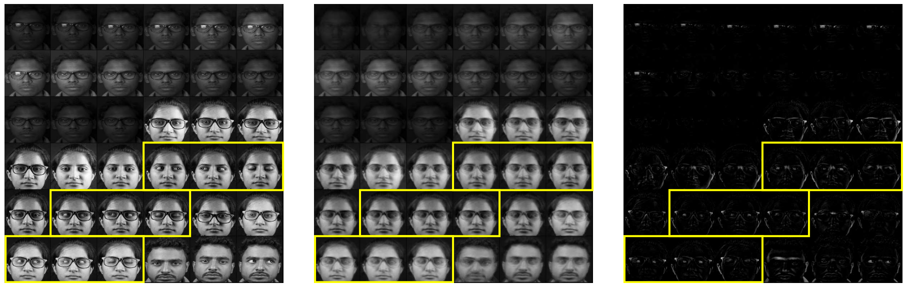
Fig. 2: Sample output images of single image based approach [17].

5.1 Multiple image approaches

[36, 51] are sample-based approaches that learn from the statistical mapping between face images with and without spectacles to generate a seamless facial image without spectacle problem. The problem with these approaches is that the representational power of these algorithms depends on the training set. [28] adopts a new hybrid approach by combining inpainting and deep learning technique for spectacle problem removal. A more generalized de-occlusion algorithm is reported in [61]. [22] is based on the assumption that facial images subjected to various illumination conditions tend to lie on a low-dimensional Lambertian space. Therefore, a given sequence of multiple images is decomposed into the Low rank and Sparse component. The low-rank layer retains most of the uncorrupted facial features while the sparse layer retains the pixels related to the spectacle problem. Even though the multiple image based approaches perform much better than the single image based approaches, one might experience the following limitations.

Limitations

- Performance of multiple based approaches depend on the facial image alignment. This is a unrealistic assumption as in real-time scenarios, the subject might continuously change his/her head position. Large head movements can cause some time-aliasing artifacts to appear in the output image.
- Because of the usage of a large number of input images: resource, computational, and time complexity of these multiple image based methods is quite large.
- The output images fail to extract the eye image dynamics (see Fig. 3). This would be a serious problem in case of eye tracking applications.



(a) (b) (c)

Fig. 3: Result of [22]. Each sub-plot contains (a) original, (b) reconstructed and (c) error component images respectively. The ineffectiveness of recovering the eye feature dynamics is highlighted in yellow.

6 Experimentation

In this section, we conduct a landmark localization experiments to highlight the impact of spectacle problem. We have considered CNN based algorithm presented in [20], for determining the influence of illumination level and spectacles on the detection accuracy of facial landmark localization. We have created a ground-truth of manually generated facial landmarks for a subset of $1,600$ images from [23] database. For a test-bench containing facial images without spectacles, the images subjected to high illumination level have least average localization error values as compared to the poorly illuminated images (Fig. 4(a)). This showcases the influence of illumination on landmark localization. Similar experiment on a test-bench of images subjected to the same illumination levels reveals that the localization error rate increases for images with spectacle problem (Fig. 4(b)).

Due to the error in landmark localization, application related to human-computer-interaction systems also suffer. In Fig. 5 we present the influence of inaccurate eye feature localization on eye-blink detection as an example.

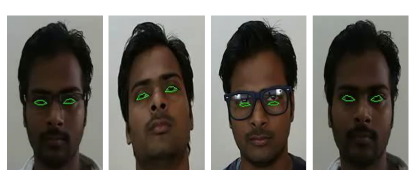


Fig. 5: Sample images highlighting the influence of spectacles on eye localization.

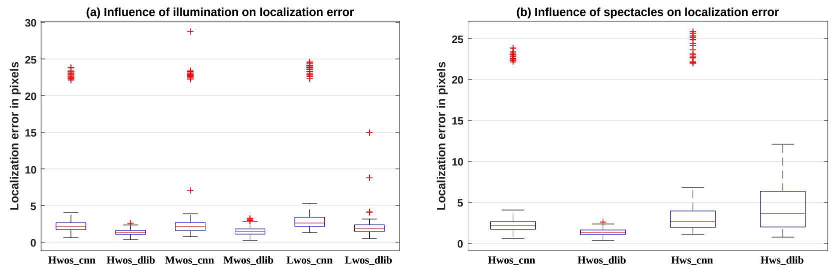


Fig. 4: Error distribution highlighting the influence of (a) illumination and (b) spectacles on the localization of face features. Where H: High, M: Medium, L: Low illumination level; wos: Without spectacles, ws: with spectacles; dlib and cnn methods as proposed in [20].

7 Conclusion

Accurate eye feature detection, localization and tracking is a preliminary but important step in the spectrum of disciplines like human-computer-interaction, biometrics, alertness-level detection applications. In this article, we attempt to present a comprehensive survey on the state-of-the-art eye corner detection techniques. The review focuses on real-life scenarios wherein the subject wear spectacles and the research challenges that comes along with it. Recent developments in the topic related to spectacle problem removal approaches is also presented and discussed. Due to the inherent complexity of the spectacle problem and its wide practical applications in science, society, research and industry, we believe that this area will draw increasing attention from a variety of fields beyond image processing and machine learning.

References

1. Alkassar, S., Woo, W., Dlay, S., Chambers, J.: Efficient eye corner and gaze detection for sclera recognition under relaxed imaging constraints. In: Signal Processing Conference (EUSIPCO), 2016 24th European. pp. 1965–1969. IEEE (2016)
2. Baback Moghaddam, A.P.P.: Face recognition using view-based and modular eigenspaces (1994). https://doi.org/10.1117/12.191877, https://doi.org/10.1117/12.191877
3. Belhumeur, P.N., Hespanha, J.P., Kriegman, D.J.: Eigenfaces vs. fisherfaces: recognition using class specific linear projection. IEEE Transactions on Pattern Analysis and Machine Intelligence **19**(7), 711–720 (Jul 1997). https://doi.org/10.1109/34.598228
4. Bengoechea, J.J., Cerrolaza, J.J., Villanueva, A., Cabeza, R.: Evaluation of accurate eye corner detection methods for gaze estimation. Journal of Eye Movement Research **7**(3) (2014), https://bop.unibe.ch/JEMR/article/view/2381
5. Burgos-Artizzu, X.P., Perona, P., Dollr, P.: Robust face landmark estimation under occlusion. In: 2013 IEEE International Conference on Computer Vision. pp. 1513–1520 (Dec 2013). https://doi.org/10.1109/ICCV.2013.191

6. Burgos-Artizzu, X.P., Zepeda, J., Clerc, F.L., Prez, P.: Pose and expression-coherent face recovery in the wild. In: 2015 IEEE International Conference on Computer Vision Workshop (ICCVW). pp. 877–885 (Dec 2015). https://doi.org/10.1109/ICCVW.2015.117
7. Cheung, Y., Peng, Q.: Eye gaze tracking with a web camera in a desktop environment. IEEE Transactions on Human-Machine Systems **45**(4), 419–430 (Aug 2015). https://doi.org/10.1109/THMS.2015.2400442
8. Dibeklioglu, H., Salah, A.A., Gevers, T.: A statistical method for 2-d facial landmarking. IEEE Transactions on Image Processing **21**(2), 844–858 (Feb 2012). https://doi.org/10.1109/TIP.2011.2163162
9. Du, C., Su, G.: Eyeglasses removal from facial images. Pattern Recognition Letters **26**(14), 2215 – 2220 (2005). https://doi.org/https://doi.org/10.1016/j.patrec.2005.04.002, http://www.sciencedirect.com/science/article/pii/S0167865505001133
10. Erdogmus, N., Dugelay, J.L.: An efficient iris and eye corners extraction method. In: Hancock, E.R., Wilson, R.C., Windeatt, T., Ulusoy, I., Escolano, F. (eds.) Structural, Syntactic, and Statistical Pattern Recognition. pp. 549–558. Springer Berlin Heidelberg, Berlin, Heidelberg (2010)
11. Fernández, A., García, R., Usamentiaga, R., Casado, R.: Glasses detection on real images based on robust alignment. Machine Vision and Applications **26**(4), 519–531 (May 2015). https://doi.org/10.1007/s00138-015-0674-1, https://doi.org/10.1007/s00138-015-0674-1
12. Gao, W., Cao, B., Shan, S., Chen, X., Zhou, D., Zhang, X., Zhao, D.: The cas-peal large-scale chinese face database and baseline evaluations. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans **38**(1), 149–161 (Jan 2008). https://doi.org/10.1109/TSMCA.2007.909557
13. Herpers, R., Michaelis, M., Lichtenauer, K.., Sommer, G.: Edge and keypoint detection in facial regions. In: Proceedings of the Second International Conference on Automatic Face and Gesture Recognition. pp. 212–217 (Quarterly 1996). https://doi.org/10.1109/AFGR.1996.557266
14. Huang, G.B., Ramesh, M., Berg, T., Learned-Miller, E.: Labeled faces in the wild: A database for studying face recognition in unconstrained environments. Tech. Rep. 07-49, University of Massachusetts, Amherst (October 2007)
15. Hwang, B.W., Roh, M.C., Lee, S.W.: Performance evaluation of face recognition algorithms on asian face database. In: Sixth IEEE International Conference on Automatic Face and Gesture Recognition, 2004. Proceedings. pp. 278–283 (May 2004). https://doi.org/10.1109/AFGR.2004.1301544
16. Jesorsky, O., Kirchberg, K.J., Frischholz, R.W.: Robust face detection using the hausdorff distance. In: Bigun, J., Smeraldi, F. (eds.) Audio- and Video-Based Biometric Person Authentication. pp. 90–95. Springer Berlin Heidelberg, Berlin, Heidelberg (2001)
17. Jia, X., Guo, J.: Eyeglasses removal from facial image based on phase congruency. In: 2010 3rd International Congress on Image and Signal Processing. vol. 4, pp. 1859–1862 (Oct 2010). https://doi.org/10.1109/CISP.2010.5647366
18. Jing, Z., Mariani, R., Wang, J.: Glasses detection for face recognition using bayes rules. In: Tan, T., Shi, Y., Gao, W. (eds.) Advances in Multimodal Interfaces — ICMI 2000. pp. 127–134. Springer Berlin Heidelberg, Berlin, Heidelberg (2000)
19. Kazemi, V., Sullivan, J.: One millisecond face alignment with an ensemble of regression trees. In: 2014 IEEE Conference on Computer Vision and Pattern Recognition. pp. 1867–1874 (June 2014). https://doi.org/10.1109/CVPR.2014.241

20. Kazemi, V., Sullivan, J.: One millisecond face alignment with an ensemble of regression trees. In: 2014 IEEE Conference on Computer Vision and Pattern Recognition. pp. 1867–1874 (June 2014). https://doi.org/10.1109/CVPR.2014.241
21. Lam, K.M., Yan, H.: Locating and extracting the eye in human face images. Pattern Recognition **29**(5), 771 – 779 (1996). https://doi.org/https://doi.org/10.1016/0031-3203(95)00119-0, http://www.sciencedirect.com/science/article/pii/0031320395001190
22. Lazarus, M.Z., Gupta, S.: A low rank model based improved eye detection under spectacles. In: 2016 IEEE 7th Annual Ubiquitous Computing, Electronics Mobile Communication Conference (UEMCON). pp. 1–6 (Oct 2016). https://doi.org/10.1109/UEMCON.2016.7777820
23. Lazarus, M.Z., Gupta, S., Panda, N.: An Indian facial database highlighting the spectacle problems. In: IEEE International Conference on Innovative Technologies in Engineering 2018 (ICITE OU) (April 2018). https://doi.org/http://hdl.handle.net/2080/2992
24. Levin, A., Weiss, Y.: User assisted separation of reflections from a single image using a sparsity prior. IEEE Transactions on Pattern Analysis and Machine Intelligence **29**(9), 1647–1654 (Sept 2007). https://doi.org/10.1109/TPAMI.2007.1106
25. Li, B.Y.L., Mian, A.S., Liu, W., Krishna, A.: Using kinect for face recognition under varying poses, expressions, illumination and disguise. In: 2013 IEEE Workshop on Applications of Computer Vision (WACV). pp. 186–192 (Jan 2013). https://doi.org/10.1109/WACV.2013.6475017
26. Li, S.Z., Chu, R., Liao, S., Zhang, L.: Illumination invariant face recognition using near-infrared images. IEEE Transactions on Pattern Analysis and Machine Intelligence **29**(4), 627–639 (April 2007). https://doi.org/10.1109/TPAMI.2007.1014
27. Li, S.Z., Yi, D., Lei, Z., Liao, S.: The casia nir-vis 2.0 face database. In: 2013 IEEE Conference on Computer Vision and Pattern Recognition Workshops. pp. 348–353 (June 2013). https://doi.org/10.1109/CVPRW.2013.59
28. Liang, A., Pathirage, C.S.N., Wang, C., Liu, W., Li, L., Duan, J.: Face recognition despite wearing glasses. In: 2015 International Conference on Digital Image Computing: Techniques and Applications (DICTA). pp. 1–8 (Nov 2015). https://doi.org/10.1109/DICTA.2015.7371260
29. Liu, D., Shen, L., Yin, Y., Li, X.: How to recognize facial images with spectacles. In: 2006 6th World Congress on Intelligent Control and Automation. vol. 2, pp. 10153–10156 (2006). https://doi.org/10.1109/WCICA.2006.1713987
30. Liu, L., Sun, Y., Yin, B., Song, C.: Local gabor binary pattern random subspace method for eyeglasses-face recognition. In: 2010 3rd International Congress on Image and Signal Processing. vol. 4, pp. 1892–1896 (Oct 2010). https://doi.org/10.1109/CISP.2010.5647554
31. Martinez, A.M.: The ar face database. CVC Technical Report24 (1998)
32. Mayaluri, Z.L., Gupta, S.: Spectacle problem removal from facial images based on detail preserving filtering schemes. Journal of Intelligent & Fuzzy Systems (Preprint), 1–11 (2019)
33. Messer, K., Matas, J., Kittler, J., Jonsson, K.: Xm2vtsdb: The extended m2vts database. In: In Second International Conference on Audio and Video-based Biometric Person Authentication. pp. 72–77 (1999)
34. Moriyama, T., Kanade, T., Xiao, J., Cohn, J.F.: Meticulously detailed eye region model and its application to analysis of facial images. IEEE Transactions on Pattern Analysis and Machine Intelligence **28**(5), 738–752 (May 2006). https://doi.org/10.1109/TPAMI.2006.98

35. Pang, Z., Wei, C., Teng, D., Chen, D., Tan, H.: Robust eye center localization through face alignment and invariant isocentric patterns. PloS one **10**(10), e0139098 (2015)
36. Park, J.S., Oh, Y.H., Ahn, S.C., Lee, S.W.: Glasses removal from facial image using recursive error compensation. IEEE Transactions on Pattern Analysis and Machine Intelligence **27**(5), 805–811 (May 2005). https://doi.org/10.1109/TPAMI.2005.103
37. Phillips, P., Wechsler, H., Huang, J., Rauss, P.J.: The feret database and evaluation procedure for face-recognition algorithms. Image and Vision Computing **16**(5), 295 – 306 (1998). https://doi.org/https://doi.org/10.1016/S0262-8856(97)00070-X, http://www.sciencedirect.com/science/article/pii/S026288569700070X
38. Sagonas, C., Antonakos, E., Tzimiropoulos, G., Zafeiriou, S., Pantic, M.: 300 faces in-the-wild challenge: database and results. Image and Vision Computing **47**, 3 – 18 (2016). https://doi.org/https://doi.org/10.1016/j.imavis.2016.01.002, http://www.sciencedirect.com/science/article/pii/S0262885616000147, 300-W, the First Automatic Facial Landmark Detection in-the-Wild Challenge
39. Samaria, F.S., Harter, A.C.: Parameterisation of a stochastic model for human face identification. In: Proceedings of 1994 IEEE Workshop on Applications of Computer Vision. pp. 138–142 (Dec 1994). https://doi.org/10.1109/ACV.1994.341300
40. Sandhan, T., Choi, J.Y.: Anti-glare: Tightly constrained optimization for eyeglass reflection removal. In: 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR). pp. 1675–1684 (July 2017). https://doi.org/10.1109/CVPR.2017.182
41. Santos, G., Proena, H.: A robust eye-corner detection method for real-world data. In: 2011 International Joint Conference on Biometrics (IJCB). pp. 1–7 (Oct 2011). https://doi.org/10.1109/IJCB.2011.6117596
42. Selinger, A., Socolinsky, D.A.: Appearance-based facial recognition using visible and thermal imagery: A comparative study. Tech. rep. (2001)
43. Sirohey, S.A., Rosenfeld, A.: Eye detection in a face image using linear and nonlinear filters. Pattern Recognition **34**(7), 1367 – 1391 (2001). https://doi.org/https://doi.org/10.1016/S0031-3203(00)00082-0, http://www.sciencedirect.com/science/article/pii/S0031320300000820
44. Song, F., Tan, X., Chen, S., Zhou, Z.H.: A literature survey on robust and efficient eye localization in real-life scenarios. Pattern Recognition **46**(12), 3157–3173 (2013)
45. Tan, P., Quan, L., Lin, S.: Separation of highlight reflections on textured surfaces. In: 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06). vol. 2, pp. 1855–1860 (2006). https://doi.org/10.1109/CVPR.2006.273
46. Thomaz, C.E.: Fei face database. online] http://fei. edu. br/˜ cet/facedatabase. html (accessed 13 March 2018) (2012)
47. li Tian, Y., Kanade, T., Cohn, J.F.: Dual-state parametric eye tracking. In: Proceedings Fourth IEEE International Conference on Automatic Face and Gesture Recognition (Cat. No. PR00580). pp. 110–115 (March 2000). https://doi.org/10.1109/AFGR.2000.840620
48. Valenti, R., Gevers, T.: Accurate eye center location through invariant isocentric patterns. IEEE Transactions on Pattern Analysis and Machine Intelligence **34**(9), 1785–1798 (Sept 2012). https://doi.org/10.1109/TPAMI.2011.251
49. Villanueva, A., Ponz, V., Sesma-Sanchez, L., Ariz, M., Porta, S., Cabeza, R.: Hybrid method based on topography for robust detection of iris center and eye corners. ACM Trans. Multimedia Comput. Commun. Appl. **9**(4), 25:1–25:20 (Aug 2013). https://doi.org/10.1145/2501643.2501647, http://doi.acm.org/10.1145/2501643.2501647

50. Wang, Y., Jang, J., Tsai, L., Fan, K.: Improvement of face recognition by eyeglass removal. In: 2010 Sixth International Conference on Intelligent Information Hiding and Multimedia Signal Processing. pp. 228–231 (Oct 2010). https://doi.org/10.1109/IIHMSP.2010.64
51. Wu, C., Liu, C., Shum, H.Y., Xy, Y.Q., Zhang, Z.: Automatic eyeglasses removal from face images. IEEE Transactions on Pattern Analysis and Machine Intelligence **26**(3), 322–336 (March 2004). https://doi.org/10.1109/TPAMI.2004.1262319
52. Xia, H., Yan, G.: A novel method for eye corner detection based on weighted variance projection function. In: 2009 2nd International Congress on Image and Signal Processing. pp. 1–4 (Oct 2009). https://doi.org/10.1109/CISP.2009.5304434
53. Xiao, Y., Yan, H.: Extraction of glasses in human face images. In: Biometric Authentication, pp. 214–220. Springer (2004)
54. Xu, C., Zheng, Y., Wang, Z.: Semantic feature extraction for accurate eye corner detection. In: 2008 19th International Conference on Pattern Recognition. pp. 1–4 (Dec 2008). https://doi.org/10.1109/ICPR.2008.4761409
55. Xu, G., Wang, Y., Li, J., Zhou, X.: Real time detection of eye corners and iris center from images acquired by usual camera. In: 2009 Second International Conference on Intelligent Networks and Intelligent Systems. pp. 401–404 (Nov 2009). https://doi.org/10.1109/ICINIS.2009.109
56. Yang, Y., Lu, Y.: A new method of the accurate eye corner location. In: Yao, J., Yang, Y., Słowiński, R., Greco, S., Li, H., Mitra, S., Polkowski, L. (eds.) Rough Sets and Current Trends in Computing. pp. 116–125. Springer Berlin Heidelberg, Berlin, Heidelberg (2012)
57. Yi, D., Lei, Z., Liao, S., Li, S.Z.: Learning face representation from scratch. CoRR **abs/1411.7923** (2014), http://arxiv.org/abs/1411.7923
58. Yi, D., Li, S.Z.: Learning sparse feature for eyeglasses problem in face recognition. Face and Gesture 2011 pp. 430–435 (2011)
59. Zhang, L.: Estimation of eye and mouth corner point positions in a knowledge-based coding system (1996). https://doi.org/10.1117/12.251289, https://doi.org/10.1117/12.251289
60. Zhang, Z., Shen, Y., Lin, W., Zhou, B.: Eye corner detection with texture image fusion. In: 2015 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA). pp. 992–995 (Dec 2015). https://doi.org/10.1109/APSIPA.2015.7415420
61. Zhao, F., Feng, J., Zhao, J., Yang, W., Yan, S.: Robust lstm-autoencoders for face de-occlusion in the wild. IEEE Transactions on Image Processing **27**(2), 778–790 (Feb 2018). https://doi.org/10.1109/TIP.2017.2771408
62. Zhou, R., He, Q., Wu, J., Hu, C., Meng, Q.H.: Inner and outer eye corners detection for facial features extraction based on ctgf algorithm. In: Information Technology for Manufacturing Systems II. Applied Mechanics and Materials, vol. 58, pp. 1966–1971. Trans Tech Publications (7 2011). https://doi.org/10.4028/www.scientific.net/AMM.58-60.1966
63. Zhu, Z., Ji, Q.: Robust real-time eye detection and tracking under variable lighting conditions and various face orientations. Computer Vision and Image Understanding **98**(1), 124 – 154 (2005). https://doi.org/https://doi.org/10.1016/j.cviu.2004.07.012, http://www.sciencedirect.com/science/article/pii/S1077314204001158, special Issue on Eye Detection and Tracking