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Research paper

Systematic Review on Ear Identification

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Abstract

Context: The topic is permitted from modern topics of interest for researchers to find logical solutions to problems of detection and recognition for ear identification. Therefore, we are looking for a solution to the problem of occlusion, detection and recognition of the person create an integrated system based on the latest research and to find new results in terms of accuracy and time and be comprehensive for everything.
Objective: To survey researchers' efforts in response to the new and disruptive technology of ear identification systems, mapping the research landscape form the literature into a coherent taxonomy.
Method: We use a systematic review as the basis for our work. a systematic review builds on 249 peer-reviewed studies, selected through a multi-stage process, from 1960 studies published between 2005 and 2017.
Results: We develop a taxonomy that classifies the ear identification systems. The results of these articles are divided into three main categories, namely review and survey article, studies conducted on ear biometrics and development of ear biometric applications.
Conclusion: The paper is, to our knowledge, the largest existing study on the topic of ear identification. This typically reflects the types of available systems. Researchers have expressed their concerns in the literature, and many suggested recommendations to resolve the existing and anticipated challenges, the list of which opens many opportunities for research in this field.

Keywords: *Ear biometrics, Ear identification, Ear recognition, Ear detection.*

1. Introduction

Biometrics is a system of identifying or verifying the identity of an individual, and it has the capability to reliably distinguish between original and fake. At present, there are numerous strategies to characterize and check the identity of a person. Biometrics offers higher authenticity than the customary techniques. A perfect biometric must be novel, changeless, widespread, and collectible. Ear biometric has good advantages over the other recognition technologies since its structure does not change due to aging and, unlike other biometrics, it is unaffected by facial expression [1].
The person, who wants to enter one of the government office would need to be authenticated in some ways such as using an identity card, an identity key, or using advanced technologies such as fingerprint, iris, retina or other techniques [2]. In all the previous methods, their efficiency is limited for reasons such as the possibility of the keys being stolen or forged cards being used. A crowd in the entrance may facilitate a way for unauthorized users to slip into those offices without the knowledge of security staff [3]. Therefore, there is a need for passive identification without knowledge of the examined person [4].

2. Systematic Review

The main key words used are "ear biometrics", "ear identification", "passive identification", "ear detection" and "ear recognition". We limited our scope to papers written in English language only. Also papers would be confined to those published from 2005 to the search date (the search was conducted in April 2017). Five databases were explored to search for articles consisting of IEEEXplorer, Web of Science (WoS), Scopus, Springer link and Science Direct.
All the papers went through three steps of filtering. In the first step of filtering, all articles unrelated to the proposal were removed. For the second step, the titles and abstracts were checked for any duplicates. Finally, we reviewed the full-text articles and discarded papers that are not within the scope of study.

3. Results

The initial query resulted in 1960 papers: 538 from IEEEXplorer, 322 from Web of Science (WoS), 543 from Scopus, 375 from Springer link, and 182 from Science Direct. From the first filtering phase, 1446 out 1960 papers were out of the scope of our study. After scanning the titles and abstracts to check for duplicates, we further excluded 21 papers. In the final full-text review to check for papers that falls within our scope, 244 papers were further excluded, and a total of 249 papers remain in the final set. The whole process is summarized in Figure 1.
Figure 2 shows the five engine boxes (IEEE Xplore, Science Direct, Scopus, Springer Link and Web of Science).
That store numerous research works and were used in this systematic review. The results of these articles are divided into three main categories, namely review and survey article, studies conducted on ear biometrics and development of ear biometric applications. Most of the studies come from IEEE Xplore which consists of 151 articles, which are divided into 4 review and survey articles, 24 studies conducted on ear biometrics and 123 papers on ear biometrics applications development.

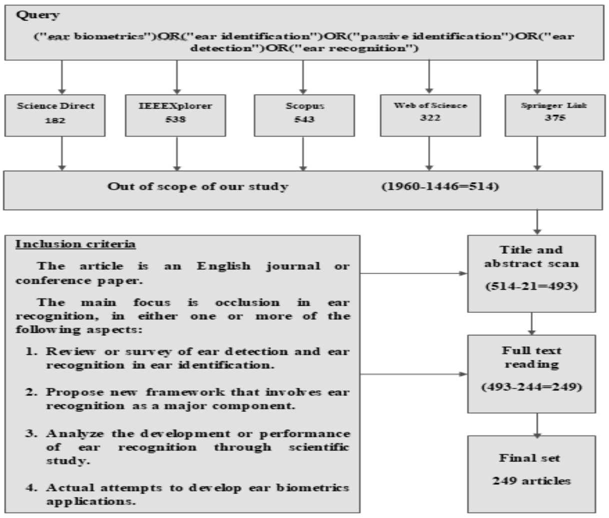

Fig. 1: Flowchart of paper selection, including the search query and inclusion criteria

As for Science Direct, there are 32 total articles where 6 papers are on ear biometrics studies and 26 papers on ear biometrics applications development. The total number of papers from Scopus is 35, further divided into 1 review and survey article, 7 on ear biometrics studies and 27 papers on ear biometrics applications development.

The least number of papers comes from Springer Link with total of 14 articles with 3 studies conducted on ear biometrics and 11 articles on ear biometrics applications development. Web of Science contributed 17 articles with 3 studies conducted on ear biometrics and 14 articles on ear biometrics applications development.

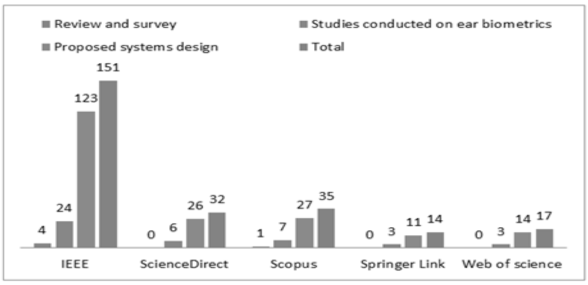

Fig. 2: Number of papers in various categories for journal publications

Figure 3 shows the papers in the four categories aforementioned according to year of publication (from 2005 to 2016). The highest number of publications was on 2013 and the least in 2006.

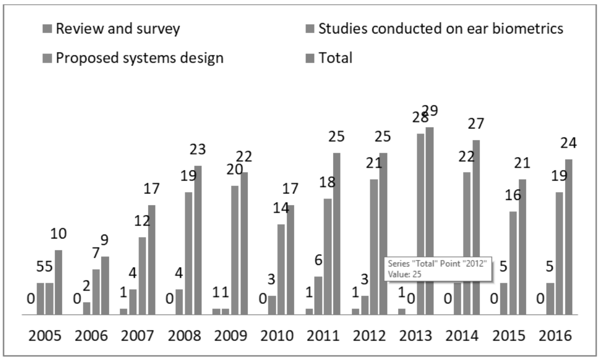

Fig. 3: Different categories by year of publication

Figure 4 displays the distribution of the studies by authors' countries, where the studies on ear biometrics were done in 34 countries. From final set of 249 articles, the geographical distribution of the selected papers on ear biometrics in terms of numbers and percentages shows that the most productive authors are from China with 84 articles followed by 34 articles from India. For further details please refer to Figure 5.

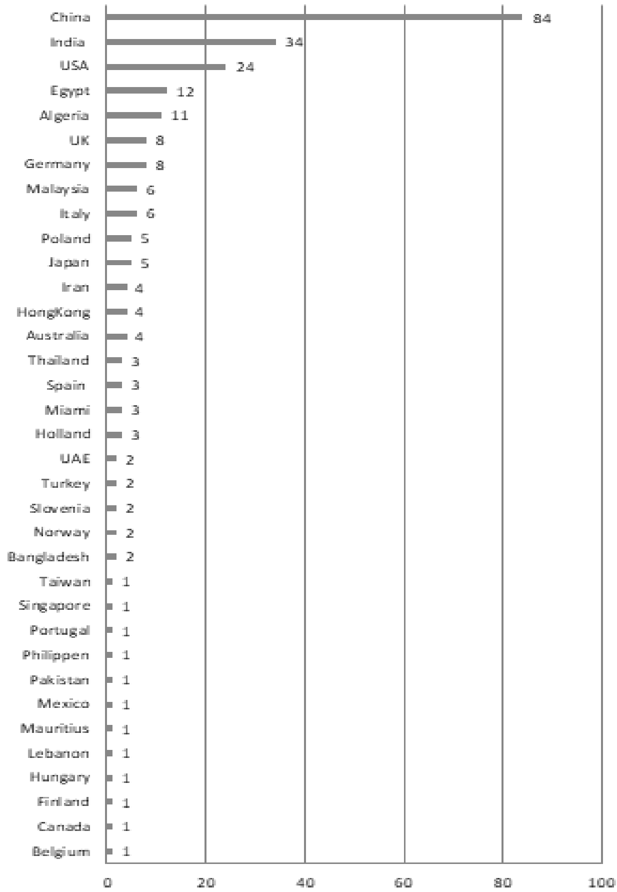

Fig. 4: Distribution by authors' countries

The selected papers were reviewed diligently to produce the taxonomy of literatures shown in Figure 5. The taxonomy centralizes the comprehensive development of different studies and implementations of main streams of research focusing on ear biometrics.

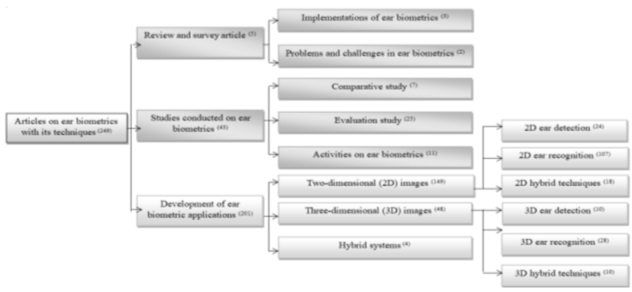

Fig. 5: Taxonomy of literature on ear biometrics

3.1 Review and Survey Articles

The first category includes survey and review article related to ear biometrics (5/249 articles) to summarize the current state of understanding on ear biometrics. The papers could be categorized to i) implementations of ear biometrics and ii) problems and challenges in ear biometrics.

3.1.1. Implementations on Ear Biometrics

In this category, there are three papers (3/5) that surveyed and reviewed the state of the art implementations of 2D and 3D ear biometrics detection and recognition systems [5], [6] and also further described about improvements of the accuracy in 2D ear recognition [7].

3.1.2. Problems and Challenges on Ear Biometrics

Two papers under this category (2/5) gave the overview of the various approaches and solutions to the problem of pattern extraction from 2D and 3D ear images [8], [9].

3.2 Studies Conducted on Ear Biometrics

The second category includes articles of studies on actual attempts to develop the ear biometrics applications (43/249 articles). These studies could further be divided into comparative studies, evaluation studies and activities of ear biometrics.

3.2.1. Comparative Study

The comparative studies were studies that developed their system and made comparison with other related studies (7/43). [10], [11] compared the performance of the system using 2D and 3D images while [12]–[14] compared their applications with other standard methods and techniques. Ear recognition and face recognition were also compared [15] and another study looked at the comparison of rotation and scaling techniques on ear images [16].

3.2.2. Evaluation Study

In the category of evaluation study of ear biometrics (25/43), ear uniqueness was studied in detail by [17]–[19]. Evaluation of feature extraction methods are also popular studies [20]–[25], as well as evaluation of various ear biometric databases and toolboxes [26]–[29]. There are studied which looked at the effect of time on ear biometrics [30], [31] and also effects of image compression on ear biometrics [32].
Other evaluation studies looked at specific issues such as evaluation of 3D ear biometric based on cumulative match characteristic (CMC) curve and the receiver operating characteristic (ROC) curves [33], new efficient feature selection scheme [34], locally linear embedding (LLE) algorithm for multi-pose ear recognition [35], use of multi-modal biometrics in recognition system [36], and performance of segmentation under various illumination conditions in 2D ear images [37]. Several studies we concerned with improvement of forensic ear identification [38], acoustic ear recognition [39], ear recognition for identification of newborn [40], also improvement by combining more biometrics in one system [41].

3.2.3. Activities of Ear Biometrics

Papers in this category were concerned with real activities and application of ear biometrics (11/43). [42]–[45] studied on authentication by using different methods and techniques, [46], [47] looked at on usage of mobile by using different methods and techniques, and [48] investigated on passive identification by using different methods and techniques. Several researchers presented overview studies on ear biometrics by using different methods and techniques [49]–[52].

3.3 Development of Ear Biometric Applications

This category presents the articles on systems that were developed for ear biometrics application (201/249). All related techniques and methods used in the actual attempts to develop and implement the ear biometrics applications are further divided into two-dimensional (2D) images, three-dimensional (3D) images and hybrid systems.

3.3.1 Two-Dimensional (2D) Images

Developments of ear biometrics applications which are based on 2D ear biometrics (149/201) are presented in this category. The techniques and methods are divided to 2D ear detection, 2D ear recognition and 2D hybrid techniques.

2D Ear Detection

The first step towards accomplishing a practical ear identification system is the ear detection from profile face images (24/149). In this step, the proposed technique will search on the ear images to locate the ear part from the image. 2D ear detection was based on various different methods. Among the popular methods proposed were:

- 2D hybrid ear detection [3], [53]–[56],
- structural ear image [57]–[59],
- AdaBoost algorithm [60]–[62],
- arc-masking extraction and AdaBoost polling [63], [64], and
- skin-color [65], [66].
- active contour model [67],
- distance transform and template matching [68],
- wavelet and principal component analysis [69],
- scale invariant feature transform algorithm [70],
- geometrical feature extraction [2], jet space similarity [71],
- Canny edge detector [72],
- Gaussian classifier [73], and
- mathematical morphology [74].

2D Ear Recognition

The richness and stability of the ear structure are the characterization of the human ear pattern that provides a large amount of information such as size, color and texture; allowing differentiation between people to identify them in recognition system. We found (107/149) articles in 2D ear recognition which uses various ear recognition methods [75]–[85]. Among the popular ear recognition methods were based on:

- sparse representation [86]–[97],
- geometric feature extraction [4], [98]–[109],
- principal component analysis PCA [110]–[116],
- neighborhood preserving embedding [117]–[119], principal independent components analysis (ICA) [120],
- neural network [121]–[127],
- wavelets [128]–[133],
- Gabor features [134]–[141],
- scale invariant feature transform (SIFT) [142]–[149],
- local binary patterns (LBP) [150]–[156],
- active shape models (ASM) [157]–[162],
- linear discriminant analysis with other methods [163]–[165],
- fisher discriminant analysis [166], [167],
- thermal profile face image [168], [169],
- support vector machine (SVM) [170], [171],
- force field transforms with other methods [172], [173],
- Poisson-Binomial Radius (PBR) [174],
- weighted wavelet transform and discrete cosine transform (DCT) [175],
- ear morphology [176],
- features histogram [177],
- One Sample per Person [178]
- partial least square discrimination (PLSD) [179], and
- isometric mapping algorithm [180].

2D Hybrid Techniques

Hybrid techniques in this category mean the proposed systems performed both ear detection and ear recognition in the same system (18/149). Among the various techniques used by researchers for performing both tasks were based on:

- geometric feature extraction method [181]–[184],
- wavelet transforms [1], [185], [186],
- scale invariant feature transform (SIFT) [187]–[189],
- contourlet transform [190], [191],
- maximum and the minimum ear height lines [192], ear identification system [193],
- kernel fisher discriminant analysis (KFDA) [194],
- Gabor scale information [195],
- unsupervised clustering [196], and
- artificial neural network [197].

3.3.2 Three-Dimensional (3D) Images

Developments of ear biometrics applications (48/201) using 3D images are presented in this category. The techniques and methods are divided to 3D ear detection, 3D ear recognition and 3D hybrid techniques.

3D Ear Detection

As stated previously, detection of the ear from profile face images is the first step in ear identification system, which also common for 3D images (10/84). Previous researchers attempted 3D ear detection based on several techniques:

- feature extraction [198]–[201],
- histograms of categorized shapes (HCS) [202], [203],
- entropic binary particle swarm optimization (EBPSO) [204],
- locating human ears in side face range images [205],
- new coordinate direction normalization schema [206],
- ear contour which combines both intensity and depth image [207].

3D Ear Recognition

We found (28/48) articles in 3D ear recognition that attempted on using the large amount of information from 3D ear image structures (such as size, color and texture) for recognition system. The following are the various approaches and techniques used:

- geometric feature extraction [208]–[211],
- 3D hybrid ear techniques [212]–[215]
- iterative closest point algorithm [216]–[221],
- Gaussian-weighted average of the mean curvature [222], [223],
- sparse representation [224], [225],
- scale invariant feature transform (SIFT) [226],
- wavelets on geometry images [227],
- structure from motion (SFM) and shape from shading (SFS) techniques [228],
- shape-based interest point descriptor (SIP) [229],
- removal of false mapped features of 3D shapes [230],
- local histograms of surface types for feature extraction [231],
- Local Salient Shape Feature [232],
- spherical harmonics transform algorithm [233],
- slice curve matching [234], and
- combination of feature embedding [235].

3D Hybrid Techniques

Similar to the same hybrid definition in 2D category, the papers in this section deals with systems that performed both ear detection and ear recognition but using 3D images (10/48). The systems were developed and implemented using the following techniques:

- histogram of indexed shapes (HIS) feature [236]–[238],
- feature extraction [239]–[241],
- iterative closest point (ICP) algorithm [242], [243],
- sparse representation [244], and
- logic scoring of preference (LSP) [245].

3.3 Hybrid Systems

In this category, the systems were developed for applications that could handle both 2D and 3D ear biometrics (4/186). The numbers are few considering that it is quite a challenging problem to have a robust and fully automatic system for 2D and 3D images with a good balance between speed and accuracy.

Hybrid multi-key point descriptor sparse representation-based classification (MKD-SRC) ear recognition approach based on 2D and 3D information were attempted by[246], [247]. [248] proposed the use of 2D AdaBoost detector that is combined with fast 3D local feature matching and fine matching via an Iterative Closest Point (ICP) algorithm while [249] proposed a fully automatic ear biometric system using 2D and 3D information.

4. Conclusion

A recent trend in ear identification is the ear biometrics systems that address ear detections and ear recognitions.

Research on this trend has already been active, and there is still a need for insight into what already happens in this emerging line at the present stage. Thus, this article aims to contribute to such vision by conducting surveys and reclassifying literature.

Specific patterns can be derived from the works done on the biometrics and the classification of the search which is divided into three distinct categories: review and survey articles, studies conducted on ear biometrics, and development of ear biometric applications. Some specialties have received more attention from researchers as well as few functions. This usually reflects the types of systems available in the wild but it gives a clear indication of where gaps exist in system development and / or evaluation.

The researchers have expressed concern in the literature, and many of the recommendations have suggested solution to the existing and expected challenges, which paves the way for other studies and research in this area. The present article focuses on improving performance and reducing arithmetic time. The proposed automated system is expected to be efficient and effective.

Few studies are found on systems that control ear detection and ear recognition to solve ear occlusion. Also, calls for an important line of research that may intersect with several other technological and scientific lines are limited.

References

[1] B. Arbab-Zavar and M. S. Nixon, “On guided model-based analysis for ear biometrics,” *Comput. Vis. Image Underst.*, vol. 115, no. 4, pp. 487–502, 2011.

[2] M. Choraś, “Ear Biometrics Based on Geometrical Feature Extraction,” *Electron. Lett. Comput. Vis. Image Anal.*, vol. 5, no. 3, pp. 84–95, 2005.

[3] N. K. A. Wahab, E. E. Hemayed, and M. B. Fayek, “HEARD: An automatic human EAR detection technique,” *Int. Conf. Eng. Technol. ICET 2012 - Conf. Bookl.*, 2012.

[4] M. Choras, “Perspective methods of biometric human identification,” *New Trends Audio Video / Signal Process. Algorithms, Archit. Arrange. Appl. SPA 2008*, vol. 16, no. 1, pp. 195–200, 2008.

[5] A. Pflug and C. Busch, “Ear biometrics: a survey of detection, feature extraction and recognition methods,” *IET Biometrics*, vol. 1, no. 2, p. 114, 2012.

[6] A. Abaza, A. Ross, C. Hebert, M. A. F. Harrison, and M. Nixon, “A Survey on Ear Biometrics,” *Acm Comput. Surv.*, vol. 45, no. 2, p. 22, 2011.

[7] F. Kurniawan, M. Shafry, and M. Rahim, “A review on 2D ear recognition,” *Proc. - 2012 IEEE 8th Int. Colloq. Signal Process. Its Appl. CSPA 2012*, pp. 204–209, 2012.

[8] P. Ramesh Kumar and K. Nageswara Rao, “Pattern extraction methods for ear biometrics - A survey,” *2009 World Congr. Nat. Biol. Inspired Comput. NABIC 2009 - Proc.*, pp. 1657–1660, 2009.

[9] M. Choras, "Image Feature Extraction Methods for Ear Biometrics--A Survey," *6th Int. Conf. Comput. Inf. Syst. Ind. Manag. Appl.*, 2007.
[10] H. Zeng, J. Y. Dong, Z. C. Mu, and Y. Guo, "Ear recognition based on 3D keypoint matching," *Int. Conf. Signal Process. Proceedings, ICSP*, pp. 1694–1697, 2010.
[11] A. Pflug, P. N. Paul, and C. Busch, "A comparative study on texture and surface descriptors for ear biometrics," *Proc. - Int. Carnahan Conf. Secur. Technol.*, vol. 2014–Octob, no. October, 2014.
[12] P. Yan and K. W. Bowyer, "Ear biometrics using 2D and 3D images," *Proc. 2005 IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, vol. 3, p. 121, 2005.
[13] Z. X. Z. Xie and Z. M. Z. Mu, "Ear recognition using LLE and IDLLE algorithm," *2008 19th Int. Conf. Pattern Recognit.*, pp. 0–3, 2008.
[14] J. Luo, Z. Mu, and Y. Wang, "Ear recognition based on force field feature extraction and convergence feature extraction," *SPIE*, vol. 7127, no. 86, p. 71272E–71272E–6, 2008.
[15] M. H. Mahoor, S. Cadavid, and M. Abdel-Mottaleb, "Multi-modal ear and face modeling and recognition," *Proc. - Int. Conf. Image Process. ICIP*, pp. 4137–4140, 2009.
[16] D. Watabe, T. Minamidani, H. Sai, and J. Cao, "Comparison of ear recognition robustness of single-view-based images rotated in depth," *Proc. - 2014 Int. Conf. Emerg. Secur. Technol. EST 2014*, pp. 19–23, 2014.
[17] P. Yan and K. W. Bowyer, "Empirical evaluation of advanced ear biometrics," *Proc. 2005 IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, p. 41, 2005.
[18] R. Purkait, "External ear: An analysis of its uniqueness," *Egypt. J. Forensic Sci.*, vol. 6, no. 2, pp. 99–107, 2016.
[19] B. S. Fabito, "Asynchronous examination security system using Ear Visual Biometric for college students," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2016–Janua, 2016.
[20] R. Cameriere, D. DeAngelis, and L. Ferrante, "Ear identification: A pilot study," *J. Forensic Sci.*, vol. 56, no. 4, pp. 1010–1014, 2011.
[21] Y. Xu and W. Zeng, "Ear recognition based on centroid and spindle," *Procedia Eng.*, vol. 29, pp. 2162–2166, 2012.
[22] R. Raghavendra, K. B. Raja, and C. Busch, "Ear recognition after ear lobe surgery: A preliminary study," *ISBA 2016 - IEEE Int. Conf. Identity, Secur. Behav. Anal.*, 2016.
[23] C. Middendorff and K. W. Bowyer, "Ensemble training to improve recognition using 2D ear," *Opt. Photonics Glob. Homel. Secur. V Biometric Technol. Hum. Identif. VI*, vol. 73061Z, pp. 1–12, 2009.
[24] P. Panchakshari and S. Tale, "Performance analysis of fusion methods for EAR biometrics," *2016 IEEE Int. Conf. Recent Trends Electron. Inf. Commun. Technol. RTEICT 2016 - Proc.*, pp. 1191–1194, 2016.
[25] A. A. Almisreb, N. M. Tahir, and N. Jamil, "Kernel graph cut for robust ear segmentation in various illuminations conditions," *ISIEA 2013 - 2013 IEEE Symp. Ind. Electron. Appl.*, pp. 71–74, 2013.
[26] R. Raposo, E. Hoyle, A. Peixinho, and H. Proença, "UBEAR: A dataset of ear images captured on-the-move in uncontrolled conditions," *IEEE SSCI 2011 - Symp. Ser. Comput. Intell. - CIBIM 2011 2011 IEEE Work. Comput. Intell. Biometrics Identity Manag.*, pp. 84–90, 2011.
[27] Z. Emersic and P. Peer, "Ear biometric database in the wild," *IWOBI 2015 - 2015 Int. Work Conf. Bio-Inspired Intell. Intell. Syst. Biodivers. Conserv. Proc.*, no. d, pp. 27–32, 2015.
[28] Z. Emersic and P. Peer, "Toolbox for ear biometric recognition evaluation," *Proc. - EUROCON 2015*, 2015.
[29] A. Abaza and T. Bourlai, "Human ear detection in the thermal infrared spectrum," *Thermosence Therm. Infrared Appl. XXXIV*, vol. 8354, p. 83540X, 2012.
[30] Y. Liu, G. Lu, and D. Zhang, "An effective 3D ear acquisition system," *PLoS One*, vol. 10, no. 6, pp. 1–14, 2015.
[31] M. Ibrahim, "The Effect of Time on Ear Biometrics," *Appl. Econ. Lett.*, vol. 18, no. 13, pp. 1201–1205, 2011.
[32] J. Widjaja, "Effects of image compression on digital specklegrams," *Opt. Lasers Eng.*, vol. 39, no. 4, pp. 501–506, 2016.
[33] H. Chen, B. Bhanu, and R. Wang, "Performance evaluation and prediction for 3D ear recognition," *Audio-and Video-Based Biometric Pers. Authentication*, pp. 748–757, 2005.
[34] L. Ghoualmi, A. Draa, and S. Chikhi, "An efficient feature selection scheme based on genetic algorithm for ear biometrics authentication," *2015 12th Int. Symp. Program. Syst.*, pp. 1–5, 2015.
[35] Z. X. Xie and Z. C. Mu, "Improved locally linear embedding and its application on multi-pose ear recognition," *Proc. 2007 Int. Conf. Wavelet Anal. Pattern Recognition, ICWAPR '07*, vol. 3, pp. 1367–1371, 2008.
[36] C. Middendorff, K. W. Bowyer, and P. Yan, "Multi-modal biometrics involving the human ear," *Proc. IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, pp. 1–2, 2007.
[37] S. El-Naggar, A. Abaza, and T. Bourlai, "On a taxonomy of ear features," *2016 IEEE Symp. Technol. Homel. Secur. HST 2016*, 2016.
[38] I. Alberink and A. Ruifrok, "Performance of the FearID earprint identification system," *Forensic Sci. Int.*, vol. 166, no. 2–3, pp. 145–154, 2007.
[39] M. Derawi, "Biometric Acoustic Ear Recognition," *IEEE*, 2016.
[40] S. Tiwari, "Newborn ' s Ear Recognition : Can it be done ?," *IEEE*, no. Iciip, pp. 9–14, 2011.
[41] M. De Marsico, M. Nappi, D. Riccio, and G. Tortora, "NABS: Novel approaches for biometric systems," *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.*, vol. 41, no. 4, pp. 481–493, 2011.
[42] A. Kumar and D. Zhang, "Ear authentication using Log-Gabor wavelets," *Biometric Technol. Hum. Identif. IV- SPIE*, vol. 6539, p. 65390A, 2007.
[43] L. Nanni and A. Lumini, "Fusion of color spaces for ear authentication," *Pattern Recognit.*, vol. 42, no. 9, pp. 1906–1913, 2009.
[44] L. Nanni and A. Lumini, "A multi-matcher for ear authentication," *Pattern Recognit. Lett.*, vol. 28, no. 16, pp. 2219–2226, 2007.
[45] N. Jamil, A. AlMisreb, and A. A. Halin, "Illumination-invariant ear authentication," *Procedia Comput. Sci.*, vol. 42, no. C, pp. 271–278, 2014.
[46] A. H. M. Akkermans, T. A. M. Kevenaar, and D. W. E. Schobben, "Acoustic ear recognition for person identification," *Proc. - Fourth IEEE Work. Autom. Identif. Adv. Technol. AUTO ID 2005*, vol. 2005, pp. 219–223, 2005.
[47] K. Iwano, T. Miyazaki, and S. Furui, "Multimodal speaker verification using ear image features extracted by PCA and ICA," *Audio- Video-Based Biometric Pers. Authentication*, vol. 3546, pp. 588–596, 2005.
[48] M. S. Ping Yan, B.S., "Ear Biometrics in Passive Human Identification," *J. Chem. Inf. Model.*, vol. 53, no. 9, pp. 1–164, 2006.
[49] L. Yuan, Z. Mu, and Z. Xu, "Using ear biometrics for personal recognition," *Adv. Biometric Pers. Authentication*, vol. 3781, no. 60375002, pp. 221–228, 2005.
[50] A. Tharwat, "Personal identification using ears based on statistical features," *Electron. Lett. Comput. Vis. Image Anal.*, vol. 14, no. 3, pp. 9–10, 2015.
[51] I. Alberink and A. Ruifrok, "Repeatability and reproducibility of earprint acquisition," *J. Forensic Sci.*, vol. 53, no. 2, pp. 325–330, 2008.
[52] A. Ross and A. Abaza, "Human ear recognition," *Computer.ORG*, vol. 44, no. 11, pp. 79–81, 2011.
[53] A. A. Almisreb and N. Jamil, "Automated ear segmentation in various illumination conditions," *Proc. - 2012 IEEE 8th Int. Colloq. Signal Process. Its Appl. CSPA 2012*, pp. 199–203, 2012.
[54] E. Gonzalez, L. Alvarez, and L. Mazorra, "Normalization and feature extraction on ear images," *Proc. - Int. Carnahan Conf. Secur. Technol.*, pp. 97–104, 2012.
[55] H. Darmstadt, "Effects of Severe Signal Degradation on Ear Detection," *Int. Work. Biometrics Forensics (IWBF), 2014*, no. 1, pp. 0–5, 2014.
[56] P. Surapong, "Framework and estimation of ear biometrics detection for digital forensic applications," *BMEiCON 2013 - 6th Biomed. Eng. Int. Conf.*, 2013.
[57] U. J. and P. G. D. Surya Prakash, "CONNECTED COMPONENT BASED TECHNIQUE FOR AUTOMATIC EAR DETECTION," *IEEE-ICIP*, vol. 1, no. c, pp. 2741–2744, 2009.
[58] S. Prakash, U. Jayaraman, and P. Gupta, "Ear localization using hierarchical clustering," *Opt. Photonics Glob. Homel. Secur. V Biometric Technol. Hum. Identif. VI*, vol. 730620, pp. 1–9, 2009.
[59] S. Prakash and P. Gupta, "An efficient ear localization technique," *Image Vis. Comput.*, vol. 30, no. 1, pp. 38–50, 2012.
[60] L. Yuan and F. Zhang, "Ear detection based on improved adaboost algorithm," *Proc. 2009 Int. Conf. Mach. Learn. Cybern.*, vol. 4, no. July, pp. 2414–2417, 2009.
[61] S. M. S. Islam, M. Bennamoun, and R. Davies, "Fast and fully automatic ear detection using cascaded adaboost," *2008 IEEE Work. Appl. Comput. Vision, WACV*, 2008.
[62] A. Abaza, C. Hebert, and M. A. F. Harrison, "Fast learning ear

detection for real-time surveillance," *IEEE 4th Int. Conf. Biometrics Theory, Appl. Syst. BTAS 2010*, 2010.

[63] A. H. Cummings, M. S. Nixon, and J. N. Carter, "A novel ray analogy for enrolment of ear biometrics," *IEEE 4th Int. Conf. Biometrics Theory, Appl. Syst. BTAS 2010*, 2010.

[64] H. C. Shih, C. C. Ho, H. T. Chang, and C. S. Wu, "Ear detection based on arc-masking extraction and AdaBoost polling verification," *IIH-MSP 2009 - 2009 5th Int. Conf. Intell. Inf. Hiding Multimed. Signal Process.*, pp. 669–672, 2009.

[65] L. Yuan and Z. C. Mu, "Ear detection based on skin-color and contour information," *Proc. Sixth Int. Conf. Mach. Learn. Cybern. ICMLC 2007*, vol. 4, no. August, pp. 2213–2217, 2007.

[66] S. Prakash, S. Prakash, U. Jayaraman, U. Jayaraman, P. Gupta, and P. Gupta, "A Skin-Color and Template Based Technique for Automatic Ear Detection," *Icapr*, pp. 213–216, 2009.

[67] A. V. Nayak, "Ear Detection using Active Contour Model," *IEEE*, 2016.

[68] U. J. and P. G. Surya Prakash, "Ear Localizatilon from Side Face images using Distance Transform and Template Matching," *Image (Rochester, N.Y.)*, no. c, 2008.

[69] M. S. Nosrati, K. Faez, and F. Faradji, "Using 2D wavelet and principal component analysis for personal identification based On 2D ear structure," *2007 Int. Conf. Intell. Adv. Syst.*, pp. 616–620, 2007.

[70] J. Jiang, H. Zhang, Q. Zhang, J. Lu, Z. Ma, and K. Xu, "Ear feature region detection based on a combined image segmentation algorithm-KRM," *Proc. SPIE*, vol. 8942, p. 89420Z–89420Z–8, 2014.

[71] K. S. and O. N. DaishiWatabe, Hideyasu Sai, "EAR BIOMETRICS USING JET SPACE SIMILARITY," *IEEE*, no. 1, pp. 1259–1264, 2008.

[72] S. Ansari and P. Gupta, "LOCALIZATION OF EAR USING OUTER HELIX CURVE OF THE EAR Saeeduddin Ansari Department of Computer Science & Engineering Indian Institute of Technology Kanpur Department of Computer Science & Engineering Indian Institute of Technology Kanpur," *IEEE Proc. Int. Conf. Comput. Theory Appl.*, pp. 1–5, 2007.

[73] A. Kumar, M. Hanmandlu, M. Kuldeep, and H. M. Gupta, "Automatic ear detection for online biometric applications," *Proc. - 2011 3rd Natl. Conf. Comput. Vision, Pattern Recognition, Image Process. Graph. NCVPRIPG 2011*, pp. 146–149, 2011.

[74] E. H. Said, A. Abaza, and H. Ammar, "Ear segmentation in color facial images using mathematical morphology," *2008 Biometrics Symp.*, pp. 29–34, 2008.

[75] L. Yuan, Z. C. Mu, and Y. Zhang, "Ear Recognition using Improved Non-Negative Matrix Factorization," *18th Int. Conf. Pattern Recognit.*, no. 2, pp. 501–504, 2006.

[76] H. Zhang and Z. Mu, "Compound structure classifier system for ear recognition," *Proc. IEEE Int. Conf. Autom. Logist. ICAL 2008*, no. September, pp. 2306–2309, 2008.

[77] Z. Zhang and H. Liu, "Multi-view ear recognition based on B-spline pose manifold construction," *Proc. World Congr. Intell. Control Autom.*, no. 1, pp. 2416–2421, 2008.

[78] B. Kocaman, "ON EAR BIOMETRICS," *IEEE*, pp. 327–332, 2009.

[79] L. Luciano and A. Krzy, "Automated Multimodal Biometrics Using Face and Ear," *Springer-Verlag Berlin Heidelb. 2009*, pp. 451–460, 2009.

[80] T. S. Chan and A. Kumar, "Reliable ear identification using 2-D quadrature filters," *Pattern Recognit. Lett.*, vol. 33, no. 14, pp. 1870–1881, 2012.

[81] S. Z. Lei and Q. Zhu, "Human Ear Recognition Using Hybrid Filter and Supervised Locality Preserving Projection," *Adv. Mater. Res.*, vol. 529, pp. 271–275, 2012.

[82] T. S. Indi and S. D. Raut, "Person identification based on multi-biometric characteristics," *2013 IEEE Int. Conf. Emerg. Trends Comput. Commun. Nanotechnology, ICE-CCN 2013*, no. Iceccn, pp. 45–52, 2013.

[83] L. Lakshmanan, "Efficient person authentication based on multi-level fusion of ear scores," *IET Biometrics*, no. May, pp. 97–106, 2013.

[84] T. S. Indi and S. D. Raut, "Person unique identification based on ear's biometric features," *2013 Int. Conf. Intell. Syst. Signal Process. ISSP 2013*, pp. 128–133, 2013.

[85] H. Huang, J. Liu, H. Feng, and T. He, "Ear recognition based on uncorrelated local Fisher discriminant analysis," *Neurocomputing*, vol. 74, no. 17, pp. 3103–3113, 2011.

[86] A. Kumar and T. S. T. Chan, "Robust ear identification using sparse representation of local texture descriptors," *Pattern Recognit.*, vol. 46, no. 1, pp. 73–85, 2013.

[87] B. Zhang, Z. Mu, C. Li, and H. Zeng, "Robust classification for occluded ear via Gabor scale feature-based non-negative sparse representation," *Opt. Eng.*, vol. 53, no. 6, p. 61702, 2013.

[88] L. Yuan, W. Liu, and Y. Li, "Non-negative dictionary based sparse representation classification for ear recognition with occlusion," *Neurocomputing*, vol. 171, pp. 540–550, 2016.

[89] G. Mawloud and M. Djamel, "Weighted sparse representation for human ear recognition based on local descriptor," *J. Electron. Imaging*, vol. 25, no. 1, 2016.

[90] M. Guermoui, D. Melaab, and M. L. Mekhalfi, "Sparse coding joint decision rule for ear print recognition," *Opt. Eng.*, vol. 55, no. 9, p. 93105, 2016.

[91] L. Yuan, C. Li, and Z. Mu, "Ear recognition under partial occlusion based on sparse representation," *Proc. 2012 Int. Conf. Syst. Sci. Eng. ICSSE 2012*, no. 1, pp. 349–352, 2012.

[92] B. Zhang, Z. Mu, H. Zeng, and S. Luo, "Robust ear recognition via nonnegative sparse representation of gabor orientation information," *Sci. World J.*, vol. 2014, 2014.

[93] R. Khorsandi, S. Cadavid, and M. Abdel-Mottaleb, "Ear recognition via sparse representation and Gabor filters," *2012 IEEE 5th Int. Conf. Biometrics Theory, Appl. Syst. BTAS 2012*, pp. 278–282, 2012.

[94] R. Khorsandi and M. Abdel-Mottaleb, "Gender classification using 2-D ear images and sparse representation," *2013 IEEE Work. Appl. Comput. Vis.*, pp. 461–466, 2013.

[95] R. Khorsandi, A. Taalimi, and M. Abdel-Mottaleb, "Robust biometrics recognition using joint weighted dictionary learning and smoothed L0 norm," *2015 IEEE 7th Int. Conf. Biometrics Theory, Appl. Syst. BTAS 2015*, 2015.

[96] B. Arab-Zavar, "Ear Recognition with Occlusion via Discrimination Dictionary and Occlusion Dictionary based Sparse Representation," *2016 12th World Congr. Intell. Control Autom. June 12-15, 2016, Guilin, China Ear*, pp. 1556–1560, 2016.

[97] R. Khorsandi and M. Abdel-Mottaleb, "EAR BIOMETRICS AND SPARSE REPRESENTATION BASED ON SMOOTHED l(0) NORM," *Int. J. Pattern Recognit. Artif. Intell.*, vol. 28, no. 8, pp. 1–24, 2014.

[98] M. Yaqubi, K. Faez, and S. Motamed, "Ear recognition using features inspired by visual cortex and support vector machine technique," *Proc. Int. Conf. Comput. Commun. Eng. 2008, ICCCE08 Glob. Links Hum. Dev.*, pp. 533–537, 2008.

[99] N. Hamdy and H. Ibrahim, "Personal Identification Using Combined Biometrics Techniques," *IEEE*, pp. 2–5, 2009.

[100] F. Saleh, A. Hamdy, and F. Zaki, "Hybrid features of spatial domain and frequency domain for person identification through ear biometrics," *Pattern Recognit. Image Anal.*, vol. 19, no. 1, pp. 35–38, 2009.

[101] A. Abaza and A. Ross, "Towards understanding the symmetry of human ears: A biometric perspective," *IEEE 4th Int. Conf. Biometrics Theory, Appl. Syst. BTAS 2010*, 2010.

[102] D. Watabe, T. Minamidani, W. Zhao, H. Sai, and J. Cao, "Effect of barrel distortion and super-resolution for single-view-based ear biometrics rotated in depth," *Proc. - 2013 Int. Conf. Biometrics Kansei Eng. ICBAKE 2013*, pp. 183–188, 2013.

[103] A. Pflug, J. Wagner, C. Rathgeb, and C. Busch, "Impact of severe signal degradation on ear recognition performance," *2014 37th Int. Conv. Inf. Commun. Technol. Electron. Microelectron. MIPRO 2014 - Proc.*, no. May, pp. 1342–1347, 2014.

[104] M. Choraś and R. S. Choraś, "Geometrical algorithms of ear contour shape representation and feature extraction," *Proc. - ISDA 2006 Sixth Int. Conf. Intell. Syst. Des. Appl.*, vol. 2, pp. 451–456, 2006.

[105] D. Shailaja and P. Gupta, "A simple geometric approach for ear recognition," *Proc. - 9th Int. Conf. Inf. Technol. ICIT 2006*, pp. 164–167, 2007.

[106] A. Basit and M. Shoaib, "A human ear recognition method using nonlinear curvelet feature subspace," *Int. J. Comput. Math.*, vol. 91, no. 3, pp. 616–624, 2014.

[107] S. Prakash and P. Gupta, "An efficient ear recognition technique invariant to illumination and pose," *Telecommun. Syst.*, vol. 52, no. 3, pp. 1435–1448, 2013.

[108] M. Z. H. Polin, A. N. M. E. Kabir, and M. S. Sadi, "2D human-ear recognition using geometric features," *2012 7th Int. Conf. Electr. Comput. Eng. ICECE 2012*, pp. 9–12, 2012.

[109] A. Morales, M. A. Ferrer, M. Diaz-Cabrera, and E. González, "Analysis of local descriptors features and its robustness applied to

ear recognition," *Proc. - Int. Carnahan Conf. Secur. Technol.*, 2014.

[110] A. F. Abate, M. Nappi, D. Riccio, and S. Ricciardi, "Ear recognition by means of a rotation invariant descriptor," *Proc. - Int. Conf. Pattern Recognit.*, vol. 4, pp. 437–440, 2006.

[111] H. Kong, H. Zhang, Z. Mu, and T. Beijing, "Ear recognition method based on fusion features of global and local features," *2008 Int. Conf. Wavelet Anal. Pattern Recognit.*, p. j, 2008.

[112] M. De Marsico, M. Nappi, and R. Daniel, "HERO_Human Ear Recognition against Occlusions," *IEEE*, pp. 178–183, 2010.

[113] M. Kus, U. Kacar, M. Kirci, and E. O. Gunes, "ARM based ear recognition embedded system," *IEEE EuroCon 2013*, no. July, pp. 2021–2028, 2013.

[114] Mamta and M. Hanmandlu, "Robust ear based authentication using Local Principal Independent Components," *Expert Syst. Appl.*, vol. 40, no. 16, pp. 6478–6490, 2013.

[115] J. Sheeba Rani and S. Jangilla, "Ear recognition using bilinear Probabilistic Principal Component analysis and sparse classifier," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, no. 1, pp. 979–983, 2016.

[116] X. Pan, Y. Cao, X. Xu, Y. Lu, and Y. Zhao, "Feature Fusion in Multimodal Recognition Based on Ear and Profile Face," *ICALIP 2008 - 2008 Int. Conf. Audio, Lang. Image Process. Proc.*, no. 1, pp. 965–969, 2008.

[117] L. Yuan, C. Li, and Z. Mu, "Ear Recognition under Partial Occlusion based on Neighborhood Preserving Embedding," *Proc. 2012 Int. Conf. Syst. Sci. Eng. ICSSE 2012*, vol. 7667, pp. 349–352, 2015.

[118] L. Yuan and Z. C. Mu, "Ear recognition based on local information fusion," *Pattern Recognit. Lett.*, vol. 33, no. 2, pp. 182–190, 2012.

[119] X. Han and Z.-C. Mu, "Multi-pose Ear Recognition Based on Improved Locally Linear Embedding," *2008 Congr. Image Signal Process.*, pp. 39–43, 2008.

[120] H.-J. Z. H.-J. Zhang, Z.-C. M. Z.-C. Mu, W. Q. W. Qu, L.-M. L. L.-M. Liu, and C.-Y. Z. C.-Y. Zhang, "A novel approach for ear recognition based on ICA and RBF network," *2005 Int. Conf. Mach. Learn. Cybern.*, vol. 7, no. August, pp. 18–21, 2005.

[121] P. L. Galdámez, A. González Arrieta, and M. Ramón Ramón, "A small look at the ear recognition process using a hybrid approach," *J. Appl. Log.*, vol. 17, pp. 4–13, 2016.

[122] L. Ghoualmi, A. Draa, and S. Chikhi, "An ear biometric system based on artificial bees and the scale invariant feature transform," *Expert Syst. Appl.*, vol. 57, pp. 49–61, 2016.

[123] D. Sánchez and P. Melin, "Optimization of modular granular neural networks using hierarchical genetic algorithms for human recognition using the ear biometric measure," *Eng. Appl. Artif. Intell.*, vol. 27, pp. 41–56, 2014.

[124] F. N. Sibai, A. Nuaimi, A. Maamari, and R. Kuwair, "Ear recognition with feed-forward artificial neural networks," *Neural Comput. Appl.*, vol. 23, no. 5, pp. 1265–1273, 2013.

[125] Z. Xie, Z. Mu, D. Sun, and D. Hu, "Multi-pose ear recognition using locally linear embedding and nearest feature line," *Comput. Simulation, Artif. Intell.*, vol. 7127, no. 2008, p. 71272A, 2014.

[126] S. Banerjee and A. Chatterjee, "Image set based ear recognition using novel dictionary learning and classification scheme," *Eng. Appl. Artif. Intell.*, vol. 55, pp. 37–46, 2016.

[127] P. C. a Lda, X. U. Zheng-guang, and S. Si, "ear recognation based on point feature," *Appl. Mech. Mater.*, vol. 380–384, pp. 3840–3845, 2013.

[128] A. Benzaoui, A. Kheider, and A. Boukrouche, "Ear description and recognition using ELBP and wavelets," *2015 1st Int. Conf. Appl. Res. Comput. Sci. Eng. ICAR 2015*, pp. 4–9, 2015.

[129] Y. W. Y. Wang, Z. M. Z. Mu, and H. Z. H. Zeng, "Block-based and multi-resolution methods for ear recognition using wavelet transform and uniform local binary patterns," *2008 19th Int. Conf. Pattern Recognit.*, pp. 0–3, 2008.

[130] H. L. Zhao, Z. C. Mu, X. Zhang, and W. J. Dun, "Ear recognition based on wavelet transform and discriminative Common Vectors," *Proc. 2008 3rd Int. Conf. Intell. Syst. Knowl. Eng. ISKE 2008*, pp. 713–716, 2008.

[131] J. Feng and Z. Mu, "Texture analysis for ear recognition using local feature descriptor and transform filter," *Pattern Recognit. Comput. Vis.*, vol. 7496, pp. 1–8, 2009.

[132] F. Kurniawan, M. S. Mohd. Rahim, and M. S. Khalil, "Geometrical and eigenvector features for ear recognition," *Proc. - 2014 Int. Symp. Biometrics Secur. Technol. ISBAST 2014*, pp. 57–62, 2015.

[133] Y. J. Zhang, M. Xiang, and Y. Tian, "An Efficient Ear Recognition Method from Two-Dimensional Images," *Adv. Mater. Res.*, vol. 1049–1050, pp. 1531–1535, 2014.

[134] A. Meraoumia, S. Chitroub, and A. Bouridane, "An automated ear identification system using Gabor filter responses," *Conf. Proc. - 13th IEEE Int. NEW Circuits Syst. Conf. NEWCAS 2015*, pp. 2–5, 2015.

[135] A. Tahmasebi, H. Pourghassem, and H. Mahdavi-Nasab, "An ear identification system using local-Gabor features and KNN classifier," *2011 7th Iran. Conf. Mach. Vis. Image Process. MVIP 2011 - Proc.*, pp. 1–4, 2011.

[136] X. Wang and W. Yuan, "Gabor wavelets and general discriminant analysis for ear recognition," *Proc. World Congr. Intell. Control Autom.*, vol. 0, no. 60672078, pp. 6305–6308, 2010.

[137] S. Z. Lei and Q. Zhu, "Human Ear Recognition Based on Phase Congruency and Kernel Discriminant Analysis," *Appl. Mech. Mater.*, vol. 241–244, pp. 1614–1617, 2012.

[138] K. Soni, U. Kumar, S. K. Gupta, and S. L. Agrwal, "A New Gabor Wavelet Transform Feature Extraction Technique for Ear Biometric Recognition," *IEEE*, no. 4, pp. 5–7, 2014.

[139] A. Kumar and C. Wu, "Automated human identification using ear imaging," *Pattern Recognit.*, vol. 45, no. 3, pp. 956–968, 2012.

[140] B. Arbab-Zavar and M. S. Nixon, "Robust log-Gabor filter for ear biometrics," *2008 19th Int. Conf. Pattern Recognit.*, pp. 1–4, 2008.

[141] Y. L. Xiao and S. P. Zhu, "Ear Recognition Based on Supervised Learning Using Gabor Filters," *Appl. Mech. Mater.*, vol. 29–32, pp. 1127–1132, 2010.

[142] J. D. Bustard and M. S. Nixon, "Robust 2D ear registration and recognition based on SIFT point matching," *BTAS 2008 - IEEE 2nd Int. Conf. Biometrics Theory, Appl. Syst.*, vol. 0, 2008.

[143] D. R. Kisku, S. Gupta, P. Gupta, and J. K. Sing, "An efficient ear identification system," *2010 5th Int. Conf. Futur. Inf. Technol. Futur. 2010 - Proc.*, pp. 0–5, 2010.

[144] J. Jiang, Q. Zhang, C. Ma, J. Lu, and K. Xu, "SIFT-based error compensation for ear feature matching and recognition system," *SPIE*, vol. 9322, p. 932210, 2015.

[145] H. Zeng, Z. C. Mu, and L. Yuan, "Ear recognition based on multi-scale features," *Proc. 2009 Int. Conf. Mach. Learn. Cybern.*, vol. 4, no. July, pp. 2418–2422, 2009.

[146] J. Zhou, S. Cadavid, and M. Abdel-Mottaleb, "Exploiting color SIFT features for 2D ear recognition," *Proc. - Int. Conf. Image Process. ICIP*, no. 4, pp. 553–556, 2011.

[147] A. Tariq and A. Anjumt, "Personal Identification Using Computerized Human Ear Recognition System," *IEEE conf*, pp. 50–54, 2011.

[148] A. S. Anwar, K. K. A. Ghany, and H. Elmahdy, "Human ear recognition using SIFT features," *Proc. 2015 IEEE World Conf. Complex Syst. WCCS 2015*, 2016.

[149] H. Zeng, Z. C. Mu, L. Yuan, and S. Wang, "Ear recognition based on the SIFT descriptor with global context and the projective invariants," *Proc. 5th Int. Conf. Image Graph. ICIG 2009*, pp. 973–977, 2010.

[150] N. B. Boodoo-Jahangeer and S. Baichoo, "LBP-based ear recognition," *13th IEEE Int. Conf. Bioinforma. Bioeng. IEEE BIBE 2013*, 2013.

[151] I. S. Youssef, A. A. Abaza, M. E. Rasmy, and A. M. Badawi, "Multimodal biometrics system based on face profile and ear," *Biometric Surveill. Technol. Hum. Act. Identif.*, vol. 9075, pp. 1–8, 2014.

[152] Z. Q. Wang and X. D. Yan, "Multi-scale feature extraction algorithm of ear image," *2011 Int. Conf. Electr. Inf. Control Eng. ICEICE 2011 - Proc.*, pp. 528–531, 2011.

[153] Z. Youbi, L. Boubchir, M. D. Bounneche, A. Ali-Cherif, and A. Boukrouche, "Human Ear recognition based on Multi-scale Local Binary Pattern descriptor and KL divergence," *2016 39th Int. Conf. Telecommun. Signal Process. TSP 2016*, pp. 685–688, 2016.

[154] A. Pflug, C. Rathgeb, U. Scherhag, and C. Busch, "Binarization of Spectral Histogram Models : An Application to Efficient Biometric Identification," *IEEE*, 2015.

[155] Y. Guo and Z. Xu, "Ear recognition using a new local matching approach," *2008 15th IEEE Int. Conf. Image Process.*, pp. 289–292, 2008.

[156] A. Benzaoui, A. Hadid, and A. Boukrouche, "Ear biometric recognition using local texture descriptors," *J. Electron. Imaging*, vol. 23, no. 5, p. 53008, 2014.

[157] L. Lu, Z. Xiaoxun, Z. Youdong, and J. Yunde, "Ear Recognition Based on Statistical Shape Model," *First Int. Conf.*

Innov. Comput. Inf. Control - Vol. I, vol. 3, 2006.
[158] F. Battisti, M. Carli, F. G. B. De Natale, and A. Neri, "Ear recognition based on edge potential function," *Image Process. Algorithms Syst. X*, vol. 8295, pp. 1–7, 2012.
[159] M. Rahman, M. S. Sadi, and R. Islam, "Human Ear Recognition Using Geometric Features," *Int. Conf. Electr. Inf. Commun. Technol.*, 2013.
[160] A. S. Anwar, K. K. A. Ghany, and H. Elmahdy, "Human Ear Recognition Using Geometrical Features Extraction," *Procedia Comput. Sci.*, vol. 65, no. Iccmit, pp. 529–537, 2015.
[161] E. Jeges and L. Maté, "Model-based human ear identification," *2006 World Autom. Congr. WAC'06*, 2007.
[162] Z. Mu, "Ear Recognition based on 2D Images," *2007 First IEEE Int. Conf. Biometrics Theory, Appl. Syst.*, no. 1, pp. 1–5, 2007.
[163] Z. Xiaoxun and J. Yunde, "Symmetrical null space LDA for face and ear recognition," *Neurocomputing*, vol. 70, no. 4–6, pp. 842–848, 2007.
[164] D. Watabe, H. Sai, K. Sakai, and O. Nakamura, "Improving the robustness of single-view ear-based recognition under a rotated in depth perspective," *Proc. - 2011 Int. Conf. Biometrics Kansei Eng. ICBAKE 2011*, pp. 179–184, 2011.
[165] X. Xu and Z. Mu, "Multimodal recognition based on fusion of ear and profile face," *Proc. 4th Int. Conf. Image Graph. ICIG 2007*, pp. 598–603, 2007.
[166] C. Murukesh, A. Parivazhagan, and K. Thanushkodi, "A novel ear recognition process using appearance shape model, fisher linear discriminant analysis and contourlet transform," *Procedia Eng.*, vol. 38, pp. 771–778, 2012.
[167] X. Pan, Y. Cao, X. Xu, Y. Lu, and Y. Zhao, "Ear and face based multimodal recognition based on KFDA," *ICALIP 2008 - 2008 Int. Conf. Audio, Lang. Image Process. Proc.*, vol. 7127, pp. 965–969, 2008.
[168] A. Abaza and T. Bourlai, "On ear-based human identification in the mid-wave infrared spectrum," *Image Vis. Comput.*, vol. 31, no. 9, pp. 640–648, 2013.
[169] S. M. Z. S. Z. Ariffin and N. Jamil, "Cross-band ear recognition in low or variant illumination environments," *Proc. - 2014 Int. Symp. Biometrics Secur. Technol. ISBAST 2014*, pp. 90–94, 2015.
[170] H. L. Wu, Q. Wang, H. J. Shen, and L. Y. Hu, "Ear identification based on KICA and SVM," *Proc. 2009 WRI Glob. Congr. Intell. Syst. GCIS 2009*, vol. 4, pp. 414–417, 2009.
[171] A. Benzaoui, N. Hezil, and A. Boukrouche, "Identity recognition based on the external shape of the human ear," *2015 1st Int. Conf. Appl. Res. Comput. Sci. Eng. ICAR 2015*, 2015.
[172] D. J. Hurley, M. S. Nixon, and J. N. Carter, "Force field feature extraction for ear biometrics," *Comput. Vis. Image Underst.*, vol. 98, no. 3, pp. 491–512, 2005.
[173] J. Dong and Z. Mu, "Multi-pose ear recognition based on force field transformation," *Proc. - 2008 2nd Int. Symp. Intell. Inf. Technol. Appl. IITA 2008*, vol. 3, no. 1, pp. 771–775, 2008.
[174] M. Swaminathan, P. K. Yadav, O. Piloto, T. Sjöblom, and I. Cheong, "A new distance measure for non-identical data with application to image classification," *Pattern Recognit.*, vol. 63, pp. 384–396, 2016.
[175] Y. Tian, D. Zhang, and B. Zhang, "Ear recognition based on weighted wavelet transform and DCT," *26th Chinese Control Decis. Conf. CCDC 2014*, no. 61202315, pp. 4410–4414, 2014.
[176] A. Benzaoui, I. Adjabi, and A. Boukrouche, "Person identification based on ear morphology," *ICAASE 2016 - Proc. Int. Conf. Adv. Asp. Softw. Eng.*, 2016.
[177] B. Houcine and D. Hakim, "Ear recognition based on Multi-bags-of-features histogram," *IEEE*, 2016.
[178] L. Chen and Z. Mu, "Partial Data Ear Recognition from One Sample per Person," *IEEE Trans. Human-Machine Syst.*, vol. 46, no. 6, pp. 799–809, 2016.
[179] H. Liu, "Multi-view ear recognition by patrial least square discrimination," *ICCRD2011 - 2011 3rd Int. Conf. Comput. Res. Dev.*, vol. 4, pp. 200–204, 2011.
[180] J. F. I. Sujuan Li, Jiangchuan Niu, "Research Into 2D Ear Recognition Based on Isomap Algorithm," *IEEE 2010 2nd Int. Conf. Ind. Inf. Syst.*, pp. 2–5, 2010.
[181] J. B. Jawale and A. S. Bhalchandra, "Ear based attendance monitoring system," *2011 Int. Conf. Emerg. Trends Electr. Comput. Technol. ICETECT 2011*, pp. 724–727, 2011.
[182] W. Xiaoyun, Y. Weiqi, and C. V. Group, "Human Ear Recognition Based on Block Segmentation," *IEEE*, pp. 262–266, 2009.
[183] S. Khobragade, D. D. Mor, and A. Chhabra, "A method of ear feature extraction for ear biometrics using MATLAB," *12th IEEE Int. Conf. Electron. Energy, Environ. Commun. Comput. Control (E3-C3), INDICON 2015*, no. 3, 2016.
[184] M. Saranya, G. L. I. Cyril, and R. R. Santhosh, "An approach towards ear feature extraction for human identification," *Int. Conf. Electr. Electron. Optim. Tech. ICEEOT 2016*, pp. 4824–4828, 2016.
[185] M. Shoaib, A. Basit, and I. Faye, "Multi-resolution analysis for ear recognition using wavelet features," *AIP Conf. Proc.*, vol. 1787, 2016.
[186] A. P. Yazdanpanah and K. Faez, "Ear recognition using bi-orthogonal and gabor wavelet-based region covariance matrices," *Appl. Artif. Intell.*, vol. 24, no. 9, pp. 863–879, 2010.
[187] B. Arbab-Zavar, M. S. Nixon, and D. J. Hurley, "On Model-Based Analysis of Ear Biometrics," *2007 First IEEE Int. Conf. Biometrics Theory, Appl. Syst.*, 2007.
[188] D. R. Kisku, H. Mehrotra, P. Gupta, and J. K. Sing, "SIFT-based ear recognition by fusion of detected keypoints from color similarity slice regions," *2009 Int. Conf. Adv. Comput. Tools Eng. Appl. ACTEA 2009*, pp. 380–385, 2009.
[189] J. D. Bustard and M. S. Nixon, "Toward unconstrained ear recognition from two-dimensional images," *IEEE Trans. Syst. Man, Cybern. Part ASystems Humans*, vol. 40, no. 3, pp. 486–494, 2010.
[190] H. Zeng, Z. C. Mu, and L. Yuan, "Contourlet transform based ear recognition," *2009 Int. Conf. Wavelet Anal. Pattern Recognition, ICWAPR 2009*, no. July, pp. 391–395, 2009.
[191] P. Ramesh Kumar and S. S. Dhenakaran, "Pixel based feature extraction for ear biometrics," *2012 Int. Conf. Mach. Vis. Image Process. MVIP 2012*, pp. 40–43, 2012.
[192] I. Omara, F. Li, H. Zhang, and W. Zuo, "A novel geometric feature extraction method for ear recognition," *Expert Syst. Appl.*, vol. 65, pp. 127–135, 2016.
[193] M. Abdel-Mottaleb and J. Zhou, "Human Ear Recognition from Face Profile Images," *Int. Conf. Adv. Biometrics*, vol. 3832 / 200, pp. 786–792, 2005.
[194] L. Yuan and Z. Mu, "Ear recognition based on gabor features and KFDA," *Sci. World J.*, vol. 2014, 2014.
[195] Y. Lin and X. Zhang, "Ear recognition based on gabor scale information," *IEEE*, pp. 14–17, 2013.
[196] A. Pflug, C. Busch, and A. Ross, "2D ear classification based on unsupervised clustering," *IJCB 2014 - 2014 IEEE/IAPR Int. Jt. Conf. Biometrics*, 2014.
[197] A. D. Dinkar and S. S. Sambyal, "Person identification in Ethnic Indian Goans using ear biometrics and neural networks," *Forensic Sci. Int.*, vol. 223, no. 1–3, 2012.
[198] S. Prakash and P. Gupta, "A rotation and scale invariant technique for ear detection in 3D," *Proc. - 2012 5th IAPR Int. Conf. Biometrics, ICB 2012*, vol. 33, no. 14, pp. 97–102, 2012.
[199] P. Chidananda, P. Srinivas, K. Manikantan, and S. Ramachandran, "Entropy-cum-Hough-transform-based ear detection using ellipsoid particle swarm optimization," *Mach. Vis. Appl.*, vol. 26, no. 2–3, pp. 185–203, 2015.
[200] J. Lei, X. You, and M. Abdel-Mottaleb, "Automatic Ear Landmark Localization, Segmentation, and Pose Classification in Range Images," *IEEE Trans. Syst. Man, Cybern. Syst.*, vol. 46, no. 2, pp. 165–176, 2016.
[201] S. Prakash and P. Gupta, "An efficient technique for ear detection in 3D: Invariant to rotation and scale," *Proc. - 2012 5th IAPR Int. Conf. Biometrics, ICB 2012*, pp. 97–102, 2012.
[202] J. Zhou, S. Cadavid, and M. Abdel-Mottaleb, "Histograms of categorized shapes for 3D ear detection," *IEEE 4th Int. Conf. Biometrics Theory, Appl. Syst. BTAS 2010*, 2010.
[203] A. Pflug, P. M. Back, and C. Busch, "Towards making HCS ear detection robust against rotation," *Proc. - Int. Carnahan Conf. Secur. Technol.*, pp. 90–96, 2012.
[204] M. R. Ganesh, R. Krishna, K. Manikantan, and S. Ramachandran, "Entropy based Binary Particle Swarm Optimization and classification for ear detection," *Eng. Appl. Artif. Intell.*, vol. 27, pp. 115–128, 2014.
[205] H. C. H. Chen and B. Bhanu, "Shape Model-Based 3D Ear Detection from Side Face Range Images," *2005 IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit. - Work.*, pp. 0–5, 2005.
[206] Chao Huang, Guangming Lu, and Yahui Liu, "Coordinate direction normalization using point cloud projection density for 3D ear," *2009 Fourth Int. Conf. Comput. Sci. Converg. Inf. Technol.*, pp. 511–515, 2009.
[207] C. Li, W. Wei, and Z. Mu, "Improved 3D ear reconstruction

based on 3D EMM," *2015 IEEE Int. Conf. Inf. Autom. ICIA 2015 - conjunction with 2015 IEEE Int. Conf. Autom. Logist.*, no. 61371142, pp. 2842–2847, 2015.

[208] S. Taertulakarn, P. Tosranon, and C. Pintavirooj, "3D ear alignment based on geometry invariant," *BMEiCON 2015 - 8th Biomed. Eng. Int. Conf.*, pp. 2–5, 2016.

[209] S. M. S. Islam, R. Davies, M. Bennamoun, R. A. Owens, and A. S. Mian, "Multibiometric human recognition using 3D ear and face features," *Pattern Recognit.*, vol. 46, no. 3, pp. 613–627, 2013.

[210] S. Cadavid and M. Abdel-mottaleb, "3-D Ear Modeling and Recognition From Video," *Ieee Trans. Inf. Forensics Secur.*, vol. 3, no. 4, pp. 709–718, 2008.

[211] G. Passalis, I. A. Kakadiaris, T. Theoharis, G. Toderici, and T. Papaioannou, "Towards fast 3D ear recognition for real-life biometric applications," *2007 IEEE Conf. Adv. Video Signal Based Surveillance, AVSS 2007 Proc.*, pp. 39–44, 2007.

[212] X. P. Sun, S. H. Li, F. Han, and X. P. Wei, "3D Ear Shape Matching Using Joint Entropy," *J. Comput. Sci. Technol.*, vol. 30, no. 3, pp. 565–577, 2015.

[213] S. Prakash and P. Gupta, "Human recognition using 3D ear images," *Neurocomputing*, vol. 140, pp. 317–325, 2014.

[214] A. A. Abaza and M. A. F. Harrison, "Ear recognition: a complete system," *Biometric Surveill. Technol. Hum. Act. Identif.*, vol. 8712, pp. 1–11, 2013.

[215] S. Cadavid, S. Fathy, J. Zhou, and M. Abdel-Mottaleb, "An adaptive resolution voxelization framework for 3D ear recognition," *2011 Int. Jt. Conf. Biometrics, IJCB 2011*, pp. 0–5, 2011.

[216] H. Liu, "Fast 3D Ear Recognition Based on Local Surface Matching and ICP Registration," *2013 5th Int. Conf. Intell. Netw. Collab. Syst.*, pp. 731–735, 2013.

[217] H. Chen and B. Bhanu, "Contour matching for 3D ear recognition," *Proc. - Seventh IEEE Work. Appl. Comput. Vision, WACV 2005*, pp. 123–128, 2007.

[218] P. Yan and K. W. Bowyer, "A fast algorithm for ICP-based 3D shape biometrics," *Comput. Vis. Image Underst.*, vol. 107, no. 3, pp. 195–202, 2007.

[219] H. Zeng, R. Zhang, Z. Mu, and X. Wang, "Local feature descriptor based rapid 3D ear recognition," *Proc. 33rd Chinese Control Conf. CCC 2014*, no. 61375010, pp. 4942–4945, 2014.

[220] S. M. S. Islam, M. Bennamoun, A. S. Mian, and R. Davies, "Score level fusion of ear and face local 3d features for fast and expression-invariant human recognition," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 5627 LNCS, pp. 387–396, 2009.

[221] P. Yan, K. Bowyer, and K. Chang, "ICP-based approaches for 3D ear recognition," *SPIE Biometric Technol. Hum. Identif.*, vol. 5779, pp. 1–10, 2005.

[222] X. Sun, G. Wang, L. Wang, H. Sun, and X. Wei, "3D ear recognition using local salience and principal manifold," *Graph. Models*, vol. 76, no. 5, pp. 402–412, 2014.

[223] S. Taertulakarn, P. Tosranon, and C. Pintavirooj, "Gaussian curvature-based geometric invariance for ear recognition," *BMEiCON 2014 - 7th Biomed. Eng. Int. Conf.*, no. 1, pp. 2–5, 2015.

[224] Z. Ding, L. Zhang, and H. Li, "A novel 3D ear identification approach based on sparse representation," *2013 IEEE Int. Conf. Image Process.*, pp. 4166–4170, 2013.

[225] S. Y. Cho, "3D ear shape reconstruction and recognition for biometric applications," *Signal, Image Video Process.*, vol. 7, no. 4, pp. 609–618, 2013.

[226] G. S. Badrinath and P. Gupta, "Feature level fused ear biometric system," *Proc. 7th Int. Conf. Adv. Pattern Recognition, ICAPR 2009*, pp. 197–200, 2009.

[227] T. Theoharis, G. Passalis, G. Toderici, and I. A. Kakadiaris, "Unified 3D face and ear recognition using wavelets on geometry images," *Pattern Recognit.*, vol. 41, no. 3, pp. 796–804, 2008.

[228] S. C. and MohamedAbdel-Mottaleb, "HUMAN IDENTIFICATION BASED ON 3D EAR MODELS," *IEEE*, 2007.

[229] J. Lei, J. Zhou, and M. Abdel-Mottaleb, "A novel shape-based interest point descriptor (SIP) for 3D ear recognition," *2013 IEEE Int. Conf. Image Process. ICIP 2013 - Proc.*, pp. 4176–4180, 2013.

[230] S. Prakash, "False Mapped Feature Removal In Spin Images Based 3D Ear Recognition," *2016 3rd Int. Conf. Signal Process. Integr. Networks False*, pp. 3–6, 2016.

[231] L. Li, L. Zhang, and H. Li, "3D EAR IDENTIFICATION USING LC-KSVD AND LOCAL HISTOGRAMS OF SURFACE TYPES," *IEEE*, 2016.

[232] X. Sun and G. Wang, "3D Ear Matching Using Local Salient Shape Feature," *2013 Int. Conf. Comput. Des. Comput. Graph.*, pp. 377–378, 2013.

[233] Y. Li, Z. Mu, and H. Zeng, "A rotation invariant feature extraction for 3D ear recognition," *2013 25th Chinese Control Decis. Conf.*, pp. 3671–3675, 2013.

[234] H. Liu and D. Zhang, "Fast 3D point cloud ear identification by slice curve matching," *ICCRD2011 - 2011 3rd Int. Conf. Comput. Res. Dev.*, vol. 4, pp. 224–228, 2011.

[235] H. Chen and B. Bhanu, "Efficient Recognition of Highly Similar 3D Objects in Range Images," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 31, no. 1, pp. 172–179, 2009.

[236] J. Zhou, S. Cadavid, and M. Abdel-Mottaleb, "An efficient 3-D ear recognition system employing local and holistic features," *IEEE Trans. Inf. Forensics Secur.*, vol. 7, no. 3, pp. 978–991, 2012.

[237] L. Zhang, L. Li, H. Li, and M. Yang, "3D ear identification using block-wise statistics based features and LC-KSVD," *IEEE Trans. Multimed.*, vol. 18, no. 8, pp. 1531–1541, 2016.

[238] J. Zhou, S. Cadavid, and M. Abdel-Mottaleb, "A Computationally Efficient Approach to 3D Ear Recognition Employing Local and Holistic Features," *IEEE Trans. Inf. Forensics Secur.*, vol. 7, no. 3, pp. 978–991, 2012.

[239] C. Ma, "A New Ear Recognition Method Based on Differential Geometry," *J. Inf. Comput. Sci.*, vol. 10, no. 18, pp. 6049–6056, 2013.

[240] Y. Liu, B. Zhang, and D. Zhang, "Ear-parotic face angle: A unique feature for 3D ear recognition," *Pattern Recognit. Lett.*, vol. 53, pp. 9–15, 2015.

[241] S. Maity and M. Abdel-Mottaleb, "3D ear segmentation and classification through indexing," *IEEE Trans. Inf. Forensics Secur.*, vol. 10, no. 2, pp. 423–435, 2015.

[242] H. Chen and B. Bhanu, "Human ear recognition in 3D," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 29, no. 4, pp. 718–737, 2007.

[243] P. Yan and K. W. Bowyer, "An automatic 3D ear recognition system," *Proc. - Third Int. Symp. 3D Data Process. Vis. Transm. 3DPVT 2006*, pp. 326–333, 2007.

[244] L. Zhang, Z. Ding, H. Li, and Y. Shen, "3D ear identification based on sparse representation," *PLoS One*, vol. 9, no. 4, pp. 1–9, 2014.

[245] G. De Tre, J. Nielandt, A. Bronselaer, D. Vandermeulen, J. Hermans, and P. Claeys, "LSP based comparison of 3D ear models," *2014 IEEE Conf. Norbert Wiener 21st Century Driv. Technol. Futur. 21CW 2014 - Inc. Proc. 2014 North Am. Fuzzy Inf. Process. Soc. Conf. NAFIPS 2014, Conf. Proc.*, 2014.

[246] L. Chen and Z. Mu, "Partial Data Ear Recognition From One Sample per Person Long," *Ieee Trans. Human-Machine Syst.*, pp. 1–11, 2016.

[247] H. Liu and J. Yan, "Multi-view ear shape feature extraction and reconstruction," *Proc. - Int. Conf. Signal Image Technol. Internet Based Syst. SITIS 2007*, pp. 652–658, 2007.

[248] S. M. S. Islam, R. Davies, M. Bennamoun, and A. S. Mian, "Efficient Detection and Recognition of 3D Ears," *Int. J. Comput. Vis.*, vol. 95, no. 1, pp. 52–73, 2011.

[249] P. Yan and K. W. Bowyer, "Biometric recognition using 3D ear shape," *Pattern Anal. Mach. Intell. IEEE Trans.*, vol. 29, no. 8, pp. 1297–1308, 2007.