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Summary and Future Work

9.1 Summary

This book has presented a complete human identification system using 3D ear biometrics. The system consists of 3D ear detection, 3D ear identification/verification and performance prediction. In the following, we provide a summary of key ideas that are presented in this book.

- For accurate localization of ear in the side face range images, a single reference 3D shape model is adapted to an image following the global-to-local registration procedure within an optimization framework. The detection starts from the extraction of regions-of-interest (ROIs) by fusion of color and range images. Once ROIs are extracted, the problem of localizing ear is converted to the alignment of the reference 3D shape model with ROIs. The alignment follows a global-to-local registration procedure. The local deformation is performed within an optimization formulation in which the bending energy of thin plate spline is incorporated as a regularization term to preserve the topology of the shape model. The optimization procedure drives the initial global registration closer towards the target. We achieved 99.3% correct detection rate on the UCR dataset and 87.71% on the UND dataset without retuning the parameters of the detection algorithm on different datasets. Furthermore, the optimization formulation is general and can be used to handle non-rigid shape registration.
- After the ear is automatically extracted from the side face range images, we proposed two different representations for surface matching.

The first representation is the ear helix/anti-helix, whose 3D coordinates are obtained from the detection algorithm; the second representation is the local surface patch (LSP) which is invariant to rotation and translation. We used these representations for finding initial correspondences between a gallery-probe pair. Then a modified iterative closest point (ICP) algorithm iteratively refined the transformation which brings the hypothesized gallery and a probe image into the best alignment. The root mean square (RMS) registration error is used as the matching error criterion. The experimental results on two real ear range and color image datasets demonstrated the potential of the proposed algorithms for robust ear recognition in 3D. Extensive experiments are performed on the UCR dataset (155 subjects with 902 images under pose variations), the UND dataset Collection F (302 subjects with 302 time-lapse gallery-probe pairs) and a subset of the UND dataset G for evaluating the performance with respect to pose variations without retuning the parameters of the proposed algorithms. These results showed that the proposed ear recognition system is capable of recognizing ears under pose variations, partial occlusions and time lapse effects. The proposed representations are less sensitive to pose variations. We also provided a comparison of the LSP representation with the spin image representation for identification and verification. This comparison showed that the LSP representation achieved a slightly better performance than the spin image representation.

- For the identification, usually the system conducts a one-to-many comparison to establish an individual's identity. This process is computationally expensive especially for a large database. Therefore, we presented a general framework for rapid recognition of 3D ears which combines the feature embedding and SVM rank learning techniques. Unlike the previous work for fast object recognition in 3D range images, we achieved a sublinear time complexity on the number of models without making any assumptions about the feature distributions. The experimental results on the UCR dataset (155 subjects with 902 ear images) and the UND dataset (302 subjects with 604 ear images) containing 3D ear objects demonstrated the performance and effectiveness of the proposed framework. The average processing time per query are 72 seconds and 192 seconds, respectively, on the two datasets with the reduction by a factor

of 6 compared to the sequential matching without feature embedding. With this speed-up, the recognition performances on the two datasets degraded 5.8% and 2.4%, respectively. We observe that the performance of the proposed algorithm is scalable with the database size without sacrificing much accuracy.
- The prediction of the performance of a biometrics system is an important consideration in the real world applications. By modeling cumulative match characteristic (CMC) curve as a binomial distribution, the ear recognition performance can be predicted on a larger gallery. The performance prediction model showed the scalability of the proposed ear biometrics system with increased database size.

In summary, the research presented in this book is focused on designing an automatic human identification system using 3D ear biometrics. The experimental results on the two large datasets show that ear biometrics has the potential to be used in the real-world applications to identify/authenticate humans by their ears.

Ear biometrics can be used in both the low and high security applications and in combination with other biometrics such as face. With the decreasing cost (few thousand dollars) and size of a 3D scanner and the increased performance, we believe that 3D ear biometrics will be highly useful in many real-world applications in the future.

9.2 Future Work

Although the algorithms we have developed achieved a good performance in 3D ear recognition, we believe that there are still some problems that need to be worked on to make automatic ear recognition system more effective and efficient in real world applications. In the following, we list the possible directions, which can improve the performance of our algorithms:

- Currently we used both color and range images for ear detection but only used 3D range image for ear recognition. Since the Minolta sensor provides us a range image and a registered color image, incorporating the color information into the recognition system can further improve the recognition performance.
- We introduced a new integrated local surface patch representation for matching 3D ears and we achieved good recognition performance on the two large datasets. However the LSP representation

only used the geometric information. It is possible to combine it with other appreance-based compact representations.

- We achieved a sublinear time complexity with respect to the size of database and the average time per query was reduced by a factor of 6. For large scale identification applications further improvement and efficient indexing techniques are desirable.
- Ear biometrics (3D and/or 2D) can be combined with (3D and/or 2D) face and side face for robust human recognition.
- It is possible to use the infrared images of ears to overcome the problem of occlusion of the ear by hair.
- Recent work in acoustic recognition allows one to determine the impulse response of an ear [113]. It is possible to combine shape-based ear recognition presented in this book with the acoustic recognition of ear [113] so as to develop an extremely fool-proof system for recognizing a live individual.
- It is possible to develop new volume based features for 3D ear recognition. Thus, one can obtain multiple representations for ear recognition.