Chapter 6

Conclusions and Future Work

This dissertation formally defines a covariate in face recognition and categorizes several challenges in face recognition as existing and emerging covariates. Figure 6.1 shows the categorization of face recognition techniques based on covariates. Existing covariates of face recognition such as pose, illumination, expression, aging, and disguise have been extensively studied and several algorithms are proposed to mitigate their effect. Apart from existing covariates, the emerging covariates such as matching sketches with digital images, faces altered due to plastic surgery, low resolution face images, and faces from videos are some new research directions in face recognition. The covariates addressed in this dissertation have recently gained attention due to their significance in law enforcement applications. One of the limitations in developing robust solutions for face recognition is the lack of large databases for these emerging covariates. The availability of publicly available large databases will allow better understanding and characterization of these covariates thus leading to better quality solutions. This dissertation presents several algorithms to address these covariates and further instigates multiple research directions.

6.1 Conclusion

In this dissertation, we first developed an automated algorithm for matching forensic sketches with digital face images. The algorithms starts by enhancing the quality of forensic sketches and digital face images to eliminate distortions and noise introduced due to the excessive use of charcoal pencil, paper quality, and scanning (device noise/errors). A multi-scale circular weber’s local descriptor (MCWLD) is proposed for encoding discriminative micro patterns from local regions of sketches and digital face images at multiple scales. Further, a memetic algorithm is developed to assign optimal weights to different local regions of face for matching using weighted $\chi^2$ distance. We also evaluated
human performance for matching sketches with digital face images and found that the information collected from individuals corroborate with our observation that local regions provide discriminating information for efficient face recognition. Comprehensive experimental evaluation on different sketch databases show that the proposed algorithm yields better identification performance compared to existing face recognition algorithms and two commercial face recognition systems. Finally, we prepared a sketch database, namely IIIT-D sketch database [51], that comprises viewed, semi-forensic, and forensic sketches for instigating further research in understanding progression from matching viewed to semi-forensic to forensic sketches.

With widespread popularity and acceptability of plastic surgery procedures, it is imperative for face recognition algorithms to efficiently match pre-and post-surgery images. We developed a multi-objective evolutionary algorithm for matching face images altered due to plastic surgery. The algorithms first generates a set of 40 non-disjoint face granules of varying shapes and sizes. Scale invariant feature transform (SIFT) and extended uniform circular local binary patterns (EUCLBP) features are extracted from different face granules and are selectively combined using evolutionary genetic algorithm. The multi-objective genetic algorithm simultaneously optimizes feature selection and weight assignment for different face granules. The evolutionary selection of feature extractor allows switching between two feature extractors (SIFT and EUCLBP) and helps in encoding discriminatory information for each face granule. We analyzed the effect of different types of plastic surgery procedures (i.e. local and global plastic surgery) and the performance
of individual face granules. Experimental evaluation under different protocols, including large scale matching, on the IIIT-D plastic surgery database [8] show that the proposed algorithm outperforms existing algorithms including a commercial system when matching surgically altered face images.

A very important law enforcement application is performing face recognition from low resolution surveillance quality images. Face recognition algorithms are generally trained for matching high resolution images and the performance is severely compromised when it encounters a situation where a low resolution probe is matched with a high resolution gallery image. We pose the problem of cross-resolution face matching as a transfer learning problem and propose a co-transfer learning framework. To facilitate knowledge transfer with probe instances in the target domain, a co-training algorithm is developed which assigns pseudo labels to the unlabeled probe instances. Cross-pollination of these two paradigms in the proposed framework enhances the performance of cross-resolution face recognition. Experiments are performed on four publicly available databases, namely, CMU Multi-PIE [9], ChokePoint [11], SCface [10], and MBGC v2 [211] databases. The performance evaluation with existing, super-resolution and commercial face recognition algorithms show the efficacy of the proposed co-transfer learning algorithm for cross-resolution face matching.

Videos provide abundant information in terms of multiple frames which capture wide intra-personal variations of an individual. This abundant information can be leveraged for efficient face recognition. This dissertation proposes a video based face recognition algorithm which computes a discriminative video signature as an ordered list of still face images. The algorithm begins by comparing each video frame with all still face images in the dictionary and generates an ordered list in which each image from the dictionary is ranked based on its similarity to the input frame. Multiple ordered lists across different video frames are combined into a composite ranked list using clustering based re-ranking and fusion algorithm. The final composite list constitutes the video signature and minimizes the distance from all the ordered lists corresponding to multiple video frames. To match two videos, their composite video signatures are compared using a normalized discounted cumulative gain measure. The nDCG measure encodes both rank in the ordered list as well as usefulness of images for characterizing the individual in the video. Experimental evaluation on the YouTube faces [6] and the MBGC v2 [211] databases under different video based face recognition scenarios such as matching still face images with videos and matching videos with videos show that the proposed algorithm outperforms existing algorithms including a commercial face recognition system.
6.2 Future Work

This dissertation offers several algorithms for emerging covariates of face recognition; however, it also instigates some future research directions for making face recognition robust and scalable. We conclude this dissertation with some possible future research directions that can be explored for addressing the emerging covariates of face recognition.

- This dissertation presents a classification of different challenges in face recognition as existing and emerging covariates. This classification is based on the maturity of a covariate in terms of how extensively it has been studied in the literature. A possible future research direction could be to have a taxonomy of these covariates beyond simple existing and emerging covariates.

- Matching sketches with digital face images has been one of the most important cues in apprehending criminals, finding missing individuals, and recognizing individuals when the face is reconstructed as a composite sketch post-mortem. It has gained significant attention from the research community and several algorithms have been proposed for matching sketches with digital face images. However, law enforcement agencies are progressively shifting from hand-drawn sketches to composite sketches which are drawn using software tools. These tools facilitate an eyewitness to select the most resembling facial template for each feature based on his/her recollection from the crime scene. Preparing composite sketches require less effort both in terms of cost as well as time as compared to hand-drawn sketches. However, the problem of matching composite sketches with digital face images is not limited to the effects of variations in composite sketches and digital face images. In real world scenarios, it is often required to match composite sketches and digital face images with age variations; e.g., in cases for finding missing individuals and recognizing individuals when the face is reconstructed as a composite sketch after death. Age variations further make this problem arduous as it changes the structural geometry and face texture. Therefore, matching composite sketches with digital face images across age variations is an important research direction. We believe that large databases with composite sketches and digital face images with age variations will lead to better understanding of the problem.

- The allure for plastic surgery is experienced worldwide and is driven by factors such as the availability of advanced technology, affordable cost and the speed with which
these procedures are performed. According to the statistics provided by the American society of aesthetic plastic surgery [101], more and more individuals are expected to undergo facial plastic surgery for cosmetic and medical reasons. Therefore, it is imperative for face recognition algorithms to be robust for matching face images altered due to plastic surgery. This dissertation presents an efficient algorithm for matching pre- and post-surgery images, however, the results and analysis inspire further research in this important area. Face recognition algorithms should be capable of automatically detecting facial regions that have variations possibly due to plastic surgery. Understanding the effects of plastic surgery in thermal-infrared imagery can be one of the possible future research direction. The research in plastic surgery is primarily focussed around a single publicly available database, IIIT-D plastic surgery database [8]. Preparing large scale databases for different types of plastic surgery procedures in visible as well as thermal-infrared imagery will lead to better understanding of the non-linear variations introduced due to plastic surgery.

• The generality of face recognition has lead to several challenging applications such as matching low resolution images from surveillance cameras. Surveillance images serve as the primary evidence in leading the investigation and recognizing the individuals at the end. It is therefore desirable to build a system where surveillance cameras coupled with a face recognition algorithm can be used to automatically identify individuals from a watch-list. The progression in face recognition has made it possible to recognize low resolution surveillance face images against watch-list database [212] to an acceptable level. However, these efforts could not foil any of the anti-social activities. One of the possible future research directions is to develop a real time face recognition algorithm coupled with surveillance system [213] that can upfront raise an alarm by identifying individuals who have committed crime or with the intent to commit crime.

• Video based face recognition has gained significant attention due to limitations of still images in addressing the wide intra-personal variations of face in many real world applications. Unlike still face images, videos provide abundant information that can be leveraged to compensate for these variations and enhance the performance of face recognition. It is our belief that videos have the potential to address face recognition in uncontrolled and unconstrained environments. The results presented in this dissertation encourages further research in video based face recognition i.e. still to video matching and video-to-video matching. Video based face recognition for identifying
an individual from a video against a watch-list requires open-set identification. One of the possible future directions, often required by law enforcement agencies, is video based face recognition in open-set scenarios where the existing research is very limited. Another possible research direction is to combine other modalities such as iris, voice, and gait for more robust identification from videos.

- Real world applications require efficient video based face recognition techniques that can identify individuals from videos captured through surveillance cameras. Currently, surveillance cameras help law enforcement agencies in tracking the activities of individuals or identifying them using manual intervention. However, an efficient low resolution face recognition system coupled with surveillance cameras can significantly speed up the accuracy and speed of this process. Therefore, developing low resolution face recognition algorithms for videos can be one of the interesting future research directions.