Chapter 8
Conclusions and future scope of work

In the present work, few techniques are proposed for the performance improvement of Fourier or frequency domain of correlation technologies designed for face recognition tasks. Initially the performance of standard and conventional correlation filters for face recognition is demonstrated and the shortcomings are delineated. Preprocessing techniques in both spatial and frequency domain is presented to improve the performance of correlation filters under illumination, occlusions and noisy conditions. Another approach of designing preferential correlation filters with class compactness and optimized parameters is evolved to improve upon the ability of handling expression and pose variations in face images. Further, a totally different projection based correlation filter is designed and phase correlation is performed in test phase. This approach helps in improving the performance during face recognition when compared to classical and standard correlation filters. A nonlinear image pixel transformation method is also evolved to get better solution for handling the problem of illumination tolerant face recognition. A technique of face detection and classification from video is presented where a modified correlation filter is used. The proposed system has the potential use in real time scenario.

Chapter-wise contributions and findings is presented in the next sections. The several areas in which the works can be extended as short term and long term research scopes are also listed.
8.1 Main contributions and findings

After a brief technology overview of correlation filters in Chapter 1, main contributions and corresponding findings of the present work regarding the performance improvement of frequency domain correlation filtering technique are listed below.

Contributions (Chapter-2)

1. A modified unconstrained correlation filter, termed as modified unconstrained minimum average correlation energy (MUMACE) filter is developed. The proposed filter is an intermediate solution of UMACE and MACH filters.

2. Spatial preprocessing is done with two kernels to emphasize high frequency components of face images and simultaneously reducing the ambiguous information.

3. Automatic generation of kernel elements are carried out using parallel architecture of generalized regression neural network (GRNN).

Findings

1. Proposed preprocessing scheme provides better classification by maximizing PSR separation of authentic and impostor face images when PIE database is used for testing.

2. ROC curves show that the improvement in probability in detection with respect to probability of false alarm with proposed technique when different subsets of YaleB database are tested.

3. Improvement in correlation planes and so also in %RR, %FAR and %EER is achieved with the proposed scheme with the face images under different occlusion conditions.
8.1. **Chapter 8**: Main contributions and findings

4. The system works very fast during testing stage when compared to standard illumination compensation algorithms.

**Contributions (Chapter-3)**

1. Wavelet modified correlation filter (WMCF) is presented. Frequency domain preprocessing is done by employing continuous wavelet filter.

2. Band pass Mexican hat wavelet filter is combined with high pass MUMACE filter. High pass MUMACE filter emphasizes the facial edges which gives better discrimination capability during face recognition. Band pass filter is also combined to achieve noise suppression capability.

3. Instead of selecting a single scale factor for Mexican hat wavelet, an optimal range of scale factor for wavelet function is selected. Because of this selection, multiple correlation approach is performed during testing phase.

4. Mainly focused on noise tolerant face recognition.

**Findings**

1. Distinct and sharp peak is found in the correlation plane for both PIE and YaleB faces when WMCF is employed and also high PSR value is obtained comparing to UMACE filter.

2. Correlation planes and ROC curves show that high recognition accuracy is achieved with WMCF under different noisy conditions of face images.

3. Better recognition performance for noisy images are observed with WMCF while comparing to existing WaveMACH filter.
Contributions (Chapter-4)

1. Mainly focuses on performance improvement of the correlation filter for recognition of faces under expression, occlusion and small pose variation.

2. During the design process of the correlation filter some preference of impostor class is given.

3. Class compactness of both types of classes is made to reduce FAR and FRR.

4. Minimization of ACE of authentic class and maximization of ACH are taken as performance criteria to reduce FRR.

5. Minimization of ACE and no maximization of ACH of impostor images are made to design the filter to reduce FAR.

6. Instead of three performance criteria as observed in the design equation of OT-MACH filter, the proposed filter minimizes five performance criteria. In addition to that the weighting factors of the performance metrics are optimized by particle swarm optimization (PSO) technique where the minimum FAR is chosen as objective function.

7. Both constrained and unconstrained optimized preferential filters are developed and their relationship is presented.

Findings

1. Better rejection capability of the preferential filter with optimized parameters is achieved during face recognition. Less %FAR at %FRR=0 is also obtained with optimized parameters of preferential filter compared to MACH, UMACE and OTMACH, when tested on Yale and AR faces.
2. Minimum %EER are found with preferential filter when random images are taken for training.

3. ROC plots ensures that preferential filter acts as better classifiers as its ROC traces step function.

Contributions (Chapter-5)

1. Class specific subspace based correlation filters are designed. Two correlation filters are developed a) optimum projecting image correlation filter designed with projecting image to the subspace b) reconstructed correlation filter with reconstructed image.

2. Individual subspace analysis is performed to minimize the residual error during reconstruction.

3. Phase correlation is done in the testing phase so that high PSR values are obtained.

4. Dynamically changing the nature of the correlation filters so that it can handle unseen illumination without increasing the training burden.

5. For the completeness of the study both 1D and 2D class specific subspace analysis are performed.

Findings

1. This technique has the ability to take perfect decision on unseen illuminated faces comparing to other standard filters as the filter’s nature depends on the projected face.

2. Correlation planes with distinct peak are found for authentic images of YaleB and PIE in case of subspace based correlation filter and high PSR values are
obtained comparing standard filters.

3. High recognition accuracy with minimum error rate is achieved in all the cases of illumination variations of face images irrespective of the training set.

Contributions (Chapter-6)

1. In addition to projection based design and phase correlation approach, a nonlinear image pixel transformation is done before synthesizing the correlation filters. Point nonlinearities are considered to extend the low gray level spanning of low intensity images into a high dynamic range.

2. Two optimum correlation filters are formed, viz a) nonlinear optimum projecting image correlation filter and b) nonlinear optimum reconstructed image correlation filter.

3. Multicorrelation approach is presented for different nonlinear variations of projecting image. From a set of correlation planes maximum PSR value is extracted for decision making.

Findings

1. Better PSR distribution, sharp peak with well suppressed sidelobes and high impostor rejection capabilities are found with these nonlinear correlation filters.

2. ROC plots shows the better illumination tolerant ability of the filters even if the information are not included in the design process.

3. High area under the curve of ROC plots with 95% confidence interval are obtained for the proposed method when standard databases like PIE and YaleB used for testing.
4. As phase correlation is implemented in testing stage, the proposed system is however sensitive to noise.

**Contributions (Chapter-7)**

1. An application of correlation filter for single frontal face detection and recognition from videos is presented.

2. A 3D unconstrained video filter termed as UVF is synthesized with frame sequences.

3. Face detection in video is evaluated by exploiting the shift invariant property of designed UVF.

4. Instead of correlating each frames, 3D correlation by 3D FFT is performed to locate the face.

5. Extracted faces are classified with the pre-trained distance classifier correlation filter (DCCF).

**Findings**

1. Face detection is fast as shift invariant property is used and no segmentation or sliding window technique is needed.

2. 3D correlation makes the system computationally expensive comparing to frame based 2D correlation approach.

3. One of the main contributions of this work is related to face detection of several persons whereas the filter is trained with only one.

4. Fast face detection and accurate recognition results suggests the usage of the proposed technique for detecting faces in real time scenario.
8.2 Future scope of works

This thesis has illustrated few effective techniques for to improve the performance of correlation filters for face recognition. The scope of future work may be divided into immediate scope and long term scope. Short term or immediate objectives of research may be stated with a view to further improve the performance to higher degree. Although sufficient theoretical explanation, mathematical descriptions and extensive experimentation are reported in support of the proposed improvement techniques, there are some limitations, can be pointed out as future scope of research.

8.2.1 Short term research scopes

1. Pose and Scale variation: All the techniques proposed in the thesis are experimented over the frontal face images (passport images) with different lighting and expression variations. But in real time face recognition, the system must perform satisfactorily well under different scale and pose variations. Ideally, theory should be developed for correlation filters in such a way so that it can handle the out of plane rotations and scale variations of face images. This is indeed a challenging task.

2. Optimal value of some parameters: Although most important parameters in many chapters are optimized, some parameters are chosen heuristically depending on experience. Attempts may be made to globally optimize all parameters used in many chapters of the present work.

3. Noise: Correlation filtering approach for face recognition, (both linear and nonlinear), using subspace based method needs further research as phase correlation used is notoriously sensitive to noise. Ideally a judicial combination of band pass filter with the subspace based filters may be one of the solutions to achieve noise tolerance under variable illumination conditions. However, this is
4. **Multiple face detection** : Face detection study includes only the localization of single face in video under constrained background. In reality, generally it occurs that one video contains multiple faces with different pose and scale variation under unconstrained background. Hence further research is needed in this area as it the one of the most difficult tasks in computer vision paradigm.

5. **Comparison with advance filters** : This study includes the comparative study of the proposed techniques only with the standard filters like UMACE, MACH, OTMACH, WaveMach, UOTSDF and some of their phase extended variants. Further research is needed to compare these results with recently developed correlation filters like ARCF, MMCF etc. In case of face detection system further research is needed to compare the results of this technique with the other members of correlation filter family like ASEF, MOSSE, MMCF etc. which are efficiently used in recent years for detection of stationary and moving objects.

### 8.2.2 Long term research scopes

Having indicated immediate tasks for future works which are beyond the scope of the present thesis, it is also worthwhile to put forward more interesting facets of face recognition as long term research goal. The connectivity between the visual perception with eye as cognitive instrument and computer vision technique with computer as processing instrument, is perhaps one of the most interesting issues in face recognition. It may be noted that many models of visual perception are evolved where mechanism of scene-eye-brain is modeled in spatio-frequency domain. However, ultimately the problem has to be related as an issue of mind-body interaction. The question arises regarding the process involved for face recognition by humans, in which brain - the material object of our body can evoke correct signals in our mind, which in turn may control many of our actions or inaction for detecting or rejecting a face. This may
inspire another useful curiosity in intelligent face detection, which may go beyond the hard scientific or technological issues, to the areas of reasoning and consciousness. In the present dissertation, the issues of realities of mind-body problem have not been touched upon, but the realities which are under the realm of technology are discussed and investigated. An attempt has been made to realize the methodologies those can detect and recognize faces, even with some deviations in a limited sense of practical world. Incidentally, the frequency domain correlation is of our interest, as this area may be the first building block of seeing and understanding by human recognition of face. The rest for detection and recognition is perhaps the coordination between visual perception, intelligence and muscle action which are related to the mind-body problems. However, one should be conscious and accept that the two kinds of realities are interdependent- which means that there can be a correlation between the two. Perhaps a day is not far off when these questions would be addressed in the language of science and physiology and translated in the domain of technology.