In this chapter we conclude by emphasizing the contributions of this research in the field of image super-resolution reconstruction. Possible future research directions for image super-resolution are also provided.

7.1 Contribution of This Research

This research addresses the problem of super-resolution image enhancement in terms of maintaining highest fidelity of reconstruction and a low computational cost to achieve maximum applicability of super-resolution to the real-world applications [80].

A novel and hybrid reconstruction scheme has been proposed for solving the problem of super-resolution restoration of high-resolution images from sequences of geometrically warped, aliased and under-sampled low-resolution images. This technique is known as the Iterative-Interpolation Super-Resolution (IISR). The proposed reconstruction scheme uses interpolation techniques to produce the first approximation of high-resolution image and then employs an iterative approach to generate the final solution. The extensive analytical data presented for the IISR system, illustrates the effectiveness and robustness of the proposed reconstruction scheme. As expected, the higher degree interpolation kernels were more accurate leading to better reconstruction but at a higher cost of computational time. The IISR scheme also contains implicit regularization features because both, the size of the interpolation kernel as well as the number of iterations, strongly affect the smoothness of the reconstructed HR image and controls the stability of the process.

For reinvestigating the influence of regularization term on the accuracy of super-resolution image reconstruction, several different forms of regularization terms were studied in this research. Detailed analysis based on the experimental data generated by using the different forms of regularization terms is also presented. In order to see the effect of the regularization parameter, $\lambda$, over the final solution, L-curve and $\lambda$-curve were considered. From our experiments, it was seen that super-resolution reconstruction was not very sensitive to the precise value of the regularization parameter when the parameter was larger than the true optimal value. This has practical implications and also explains why in many simulations good reconstructions were achieved with regularization parameter chosen in an ad hoc manner. However, because our simulations were limited only to several examples of imagery the observed insensitivity of the super-resolution reconstruction to the exact value of $\lambda$ may not be a universal property.
Taking the advantage of the detailed analysis of the regularization term, the accuracy and efficiency of the IISR technique is evaluated by comparing it against the optimization technique using the best possible regularization term. After conducting several computer experiments, it was observed that the IISR reconstruction was reasonably accurate and that further improvement by the optimization procedure was relatively small and computationally expensive. The analysis also illustrate that for a faster convergence of the optimization procedure, the final IISR solution should be used as an initialization or starting point instead of a blank input HR image.

To address the applicability of super-resolution techniques in a real world computer vision application, accurate alignment of all geometrically warped, aliased and under-sampled low-resolution frames is mandatory. A hierarchical architecture motion estimation technique based on [5] is adopted and implemented for accurate estimation of relative motion between the rotated and translationally shifted, aliased, under-sampled, low-resolution frames. Even in the case of noise contaminated low-resolution frames, hierarchical motion estimation scheme ensures accurate estimation of angle of rotation and translational shifts for precise alignment. Using a coarse-to-fine refinement strategy along with the pyramid architecture, the registration technique comparatively has a low computational cost. The technique therefore proves to be well-suited, to be incorporated with the proposed fast and efficient IISR scheme, to provide a complete super-resolution image reconstruction package.

It cannot be emphasized more, that for the implementation of super-resolution reconstruction technique in a real environment, how important it is to maintain a proper balance between improving spatial resolution and keeping the computational time low. The proposed IISR system requires a relatively small number of low-resolution images for efficient reconstruction. Good results were obtained with only 10 LR frames for magnification factors as large as 20. This is important for practical applications, because if a large number of low-resolution images were required the accumulation of errors would impede the reconstruction accuracy. In order to evaluate the robustness of the proposed IISR system, all computer simulations and analytical data presented in this research were produced using noiseless and noise contaminated, aliased and under-sampled, low-resolution frames. Also, since each iteration in the IISR scheme only requires simple operations the technique is fast and computationally efficient. With further development, the technique certainly is promisingly suitable for hardware implementation for real-time processing.

Lastly, two major professional software frameworks, IISR and ISRO, have been presented in this work based on our research. To achieve maximum flexibility and usability, the softwares have been made modular and GUIs have been created using MATLAB’s GUIDE. Both softwares serve the purpose of being standalone super-resolution image reconstruction packages. They can also be utilized as experimental tools for comparing the accuracy of reconstruction by generating high-resolution images, using different interpolation kernels in the IISR package or different combinations of the regularization term, $\lambda$ and $Q$, in the ISRO package. With further development, both the software packages, IISR and ISRO,