CHAPTER 9

CONCLUSIONS AND DIRECTIONS FOR FUTURE WORK

9.1. Conclusions

Cephalometry is an essential clinical and research tool in orthodontics. It has been used for decades to obtain absolute and relative measures of the craniofacial skeleton. Since manual identification of predefined anatomical landmarks is a very tedious approach, there is a strong need for automated methods. The task of automatically locating cephalometric landmarks has been undertaken by few independent researchers with different levels of success. The work presented in this thesis is an attempt to improve the accuracy and reliability of automatically detected cephalometric landmarks irrespective of the quality of the cephalograms.

High quality cephalograms with clear dental and skeletal structures are essential for cephalometry. However, these dental X-rays generally suffer from low signal to noise ratio and low contrast. In most automatic landmark detection algorithms image enhancement is the first step. These algorithms use traditional image enhancement methods to preprocess the images before landmark detection. However, these enhancement methods sometimes give enhanced images that are poor representations of the original information. This affects the precision of landmark detection. The enhancement techniques need to be used with caution in computer vision applications in which quantitative data is extracted from the images. In this research work, we propose two new enhancement techniques that improve the signal to noise ratio and contrast of cephalograms without loss of any useful information.

The proposed noise suppression algorithm gives good improvement in PSNR while retaining the important image structural and edge information. The algorithm gives an average PSNR of 36.34, MSSIM of 96.4 and FOM of 0.985. The values given by one of the best state-of-the-art methods BM3D are: average PSNR of 41.37, MSSIM of 0.973 and FOM of 0.962. Though BM3D method gives higher value of PSNR, comparable value of MSSIM, but a lower value of FOM. This suggests that important edge information is changed to a higher degree by BM3D than the proposed algorithm. Edge information is very significant for cephalometric landmark detection and thus the proposed algorithm is more suitable for cephalograms.

Existing techniques for automatic cephalometric analysis use histogram equalization for image enhancement. Traditional histogram equalization technique suffers from excessive enhancement, lack of brightness preservation and spikes. Thus, this lead to loss of some information in cephalograms, may give it unnatural or washed-out appearance. A modified histogram based adaptive histogram equalization technique is proposed that preserves the image brightness, improve the visibility of details without adding any artifacts and give very natural looking enhanced images. The performance of the proposed algorithm is considerably better than other recently proposed techniques. When compared with contrast-limited adaptive histogram equalization that is one of the best techniques, it gives an improvement both in EME and H. Contrast-limited adaptive histogram equalization gives an average EME of 5.979 and average H of 6.98 whereas the proposed method gives an improved average EME of 6.758 and higher value of average H at 7.08. The brightness is well preserved and is comparable to contrast-limited adaptive histogram equalization.

Image edges are the commonly used low level features used in image analysis. Two techniques for edge detection are developed and implemented. A hybrid pixel level edge detector using fuzzy logic and mathematical morphology is proposed. The proposed algorithm gives better results than Canny or Susan for cephalogram edge detection. The second method implements subpixel level edge detection using pseudo-Zernike moments with good subpixel location accuracy. The derived edge results are still not reliable enough for use in landmark detection owing to the complex nature of cephalograms. Therefore, these cannot be used for this purpose.

In this thesis work two new algorithms are developed and implemented for automatic landmark detection. For detecting the landmarks, we are interested in finding the shape information from the cephalograms that helps in the localization of landmarks. Region based descriptor describes the shape of an object in an image very efficiently. Thus in the first proposed algorithm Zernike moment based global features are used for initial landmark estimation. In the next step, local template matching is applied using ring and central projection method to find the coarse position of landmarks. Finally, to find the exact location of landmarks, template matching using a combination of SSD and NCC is applied in a small search window around the landmarks detected in Step II. The system was tested on 18 commonly used landmarks. 89% of the located landmarks are within a window of ≤ ±2 mm with the average ME of 1.86 mm and standard deviation of ME of 1.24 mm for 18 landmarks.

The computational complexity of ZMs is high. The second proposed algorithm explores a reduction in the computational complexity and further improves the landmark detection accuracy. The ART transform has the same characteristics as the ZM moments. In addition, it is computationally very fast and the high order transforms to do not suffer from numerical instability. In the proposed algorithm, ART region descriptor is used for global image matching to estimate landmark locations. With the help of these locations, the search window for each landmark is selected. Local template matching using a fused similarity measure (FSM) based on SSD, and NCC is applied on each of these search windows to extract probable landmark positions. Finally, ART feature based template matching is applied to find the best match from these probable locations. Hierarchical template matching is used to desensitize against scale and shape distortion with multiple templates for each landmark. DoG is used to suppress nonuniform illumination effects and noise and further improve the detection results. The results of the proposed algorithm are compared with other promising techniques and gives either comparable or better results. 92% of the localized landmarks lie within a window of ≤ ±2 mm, average ME for the 18 landmarks is 1.49 mm, and average standard deviation of ME is 1.25 mm. It gives 3% improvement in landmark detection accuracy from the previous proposed technique.

Table 9.1: ME for 18 Landmark in mm obtained using two proposed algorithms.

ME	Pr	Sella	Na	Or	Pns	Ans	Go	Uie	Me
Proposed Algorithm (ZM)	1.57	1.26	2.30	1.64	2.20	1.93	1.77	2.15	1.94
Proposed Algorithm (ART)	1.33	1.46	1.78	1.75	1.78	1.49	1.7	1.47	1.28
ME	Sor	Cd	Prn	Rgn	Pog	A	B	Ls	Li
Proposed Algorithm (ZM)	2.17	2.95	1.58	1.97	1.34	1.59	2.18	1.11	1.83
Proposed Algorithm (ART)	2.15	2.05	1.11	1	0.71	1.38	1.65	1.37	1.31

From Table 9.1 it becomes clear that ART based algorithm gives significantly improved results for landmarks Uie, me, Prn, Rgn, and Pog. There is some improvement in the detection of landmarks like Pr, Pns, Ans, Cd, A, B and Li. The ZM based proposed algorithm gives slightly better results for landmarks $Sella$, Or and Ls.

Table 9.2: SD for 18 Landmark in mm obtained using two proposed algorithms.

SD	Pr	Sella	Na	Or	Pns	Ans	Go	Uie	Me
Proposed Algorithm (ZM)	0.95	1.11	0.90	1.13	1.77	1.12	1.02	0.97	0.91
Proposed Algorithm (ART)	0.97	0.95	1.77	1.34	1.53	1.50	1.08	1.34	0.85
SD	Sor	Cd	Prn	Rgn	Pog	A	B	Ls	Li
Proposed Algorithm (ZM)	1.02	2.19	1.36	1.29	0.89	1.24	1.36	2.07	1.07
Proposed Algorithm (ART)	2.04	2.09	0.82	1.12	0.63	0.97	1.68	0.99	0.89

For most landmarks, ART based method gives better SD. The average SD for both the methods is nearly same. The problem is very challenging. Each landmark is unique with its own set of features and level of complexity. Optimizing the algorithm for one landmark may affect the accuracy of some other landmarks.

Finally, recently proposed PCET features are compared with ZM and ART features to analyze their effectiveness in cephalometric landmark detection. Through experiments, it is observed that PCET is most effective for global matching of cephalograms. A fast technique for the computation of PCET is proposed. The proposed algorithm provides a speed enhancement by a factor between 3 and 4, which is a significant improvement over the existing fast method.

9.2. Future Research Directions

In this thesis we have focused on cephalogram enhancement techniques and detection of landmarks using template matching methodology. We have employed the global image descriptors, such as the moments and the transforms, for the matching purpose. In future, a combination of global and local image descriptors will be investigated. The use of fast PCET feature in combination with fast PCT and PST feature can be explored for further improving the accuracy of landmark detection. The recently developed local binary patterns are becoming increasingly popular for the analysis of textured images. This local descriptor is likely to provide good results for cephalometric landmark detection because contours and textures are equally important for accurate detection of landmarks. Therefore, our future work will concentrate on the detection of landmarks using local binary patterns template matching techniques.

The introduction of cone beam CT (CBCT) has made 3D imaging more readily available for dental applications. The advantages of CBCT include low radiation dose and high spatial resolution. The performance of the proposed techniques needs to be analyzed on CTBT data set.