ABSTRACT

The diagnostic value of cephalometric analysis depends on the accurate and reproducible identification of clearly defined landmarks on cephalometric radiographs. Manual landmark detection is a very monotonous and time intensive process. It takes around thirty minutes for an orthodontist to analyze one cephalogram using his training and experience. Computer technology is having an increasing impact on the practice of orthodontics. The demand of computerized cephalometric landmark detection, which is a sub field of computer vision, is rising due to the advances, affordability and increased use of digital images in the fields of medicine. It will considerably increase the efficiency of orthodontists if the landmark detection operation could be performed automatically using a personal computer rather than manually. Such a system will reduce the subjectivity involved due to intra and inter examiner variability and save valuable clinical time.

Automatic cephalometric analysis has been a subject of research for the past 25 years and attempts to automate the localization of landmarks have been attempted by many researchers with varying degree of success. Although some significant work has been done, there are still some problems, which need to be solved. Previous attempts at locating landmarks have had a limited success. More sophisticated techniques are still required to improve the accuracy of the landmark detection results. The principal difficulty in identifying the landmarks are the poor diagnostic quality of a cephalometric radiograph, large variations in biological features of the patient's skull structure (hard and soft tissues), abnormalities, overlapped complex structures and areas with subtle changes in grayscale.

The main aim of our research is to develop an algorithm or a combination of algorithms, which can efficiently and effectively enhance the cephalograms by improving the contrast and reducing the noise and find all the landmarks automatically, has greater

ability to cope with a large variety of biological shapes and is successful when tested on a large number of test images.

A good quality cephalogram is needed to clearly show dental and skeletal structures. The quality of cephalogram is affected by underexposure or overexposure. High-quality cephalograms should not be obtained at the price of exposing the patient to higher X-ray dose or multiple exposures to X-rays. These rays have harmful effects on the body and may cause cancer. Thus in order to avoid this image enhancement can be applied to improve the quality of the X-ray. This will help in better interpretation of meaningful details in the cephalograms and improve the accuracy of automatic cephalometric analysis methods.

Cephalometric X-rays suffer from Poisson's noise besides Gaussian noise. Gaussian noise suppression methods are well-established and are widely used. But it is more difficult to remove Poisson's noise that is multiplicative in nature. Generally, the Poisson noise is converted to additive Gaussian noise before applying any noise suppression method. Most techniques for noise suppression, cause blurring or dislocation of edges. Thus, these techniques adversely affect the accuracy of landmark detection. A novel noise suppression technique is presented that significantly improves the image quality while preserving the edge information. In the proposed algorithm variance stabilizing transform is used to convert Poisson's noise to Gaussian noise before the application of nonlinear diffusion filter to suppress the noise. The method gives significantly improved peak signal to noise ratio while preserving the image structure.

Cephalometric X-rays may have low contrast caused by factors like suboptimal settings, capability of the used imaging device in developing the maximum contrast, reduction in contrast caused by blurring owing to the scattered radiations. Histogram equalization is a widely used technique for contrast enhancement. In this technique, the histogram is computed using the frequency of gray levels in the image. The traditional histogram equalization is a global technique, which sometimes leads to excessive contrast enhancement. That may cause extreme modifications on the histogram, resulting in visual artifacts and giving the image an unnatural look. In addition, the properties of pixels in an image vary spatially, thus using a single global mapping derived from its histogram cannot enhance the local contrast optimally. In diagnostic medical images, local details are more important than global contrast. However, the frequency of the gray levels is not always consistent with their contribution to the representation of the image. Maximum information in an image is carried in its edges. Corresponding to the gradient value of pixels, they may be assigned different weights before the computation of the histogram. This modified histogram when used with global or local histogram equalization techniques gives better enhancement results. An efficient algorithm for cephalogram contrast enhancement is proposed that uses modified histogram with adaptive histogram equalization. The modified histogram is derived using detailed coefficients obtained by applying stationary wavelet transform with biorthogonal spline wavelets to the images. The results of the proposed algorithm are promising and enhance the cephalogram without loss of image detail or addition of artifacts. The mean brightness of the image is not affected, and the enhanced images have a natural look. Image sharpness is also improved when the contrast is enhanced.

The edge based techniques are simple to understand and implement and are thus used in several existing automatic landmark detection techniques. Edge detection and tracing is used to locate the landmarks on the edges. But due to poor-quality and complex nature of cephalograms gradient based edge detectors may miss wanted edges or may detect noise as edges. Fuzzy logic allows to model uncertainty and subject concepts in a better form than crisp models. It can deal with situations in, which making a sharp distinction between the boundaries is difficult as in case of image edges. Mathematical morphology provides an alternative approach to image processing using the shape concept stemmed from set theory. The basic morphological operations are widely used for edge thinning. Based on this observation, in this work, a hybrid edge detector using fuzzy and mathematical morphology is proposed. The algorithm follows a two-step procedure. In the first step, edges are detected by using fuzzified image and simple rules. In the second step edged are thinned using mathematical operators. The technique gives better results than other fuzzy techniques for edge detection and standard techniques like Canny and Susan. To further improve the landmark detection accuracy subpixel edge detection was investigated and a new method for subpixel edge has been proposed using pseudo-Zernike moments. Though, the edge detection results given by the two proposed techniques are better than existing techniques, still the results are not completely reliable for use in landmark detection.

Many researchers have studied cephalometric analysis from the perspective of image processing and have tried to automate it. Locating the landmarks (both on bony structure and soft tissue) on X-ray images is a challenging task since the images lack hard edges, suffer from shadows and noise and outline are not clearly defined. The objects in the cephalogram are magnified by different amounts owing to divergence of X-ray photons resulting in double edges. High kilovolt setting of the X-ray gives better density as it can penetrate hard bony structure but low contrast between the bony structure and the soft tissue whereas low kilovolt setting gives better contrast but low density. The cephalograms may suffer from image blurring caused by movement of the patient. Furthermore, any X-ray photon whose initial direction is scattered by patient's hard and soft tissues may create image noise.

We propose two methods to automatically detect the landmarks both on the soft tissue and bony structures. The first method explores the use of Zernike moment based global features for initial landmark estimation and finding small expectation window for each landmark. Using this expectation window and local template matching based on ring and central projection method a closer approximation of landmark position is obtained. A smaller search window based on this approximation is used to find the exact location of landmark positions based on template matching using a combination of sum of squared distance and normalized cross correlation. The proposed algorithm was tested on 18 commonly used landmarks. 89% of the localization of 18 selected landmarks is within a window of ±2 millimeters (mm).

In the second automatic cephalometric landmark detection algorithm angular radial transform region descriptors are used to estimate landmark locations on the query image. The derived landmark positions help in the selection of search window for each landmark. Local template matching using a fused similarity measure based on sum of squared distance, and normalized cross correlation is applied on each search window to extract probable landmark positions. Finally, angular radial transform 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. Difference of Gaussian filter is used to suppress non uniform illumination effects and noise and further improve the detection results. The second proposed algorithm gives an accuracy of 92% for the 18 selected landmarks. After preprocessing the cephalometric image, image registration is the first step in most hybrid automatic cephalometric landmark detection algorithms. This step helps find the approximate landmark locations. Most similar images to the query image are found from the training set images. The average location of landmarks acquired from the 5% most similar manually marked training set images are considered the initial approximate locations of landmarks for the query image.

A search window around these locations is further used to find the exact landmark locations in the test cephalogram. The later part of the thesis analyzes the relative performance of polar complex exponential transform to the other region shape descriptors used for global matching of cephalometric images. Zernike moment shape descriptor has proved its superiority with respect to description capability and robustness to noise or deformations over other moment functions. A relatively small set of Zernike moments can characterize the global shape of a pattern effectively. Thus initially we used Zernike moments for cephalometric image registration. However, their computational complexity is high. Angular radial transform has the same characteristics as the moments, minimum information redundancy, and robustness to image noise and invariant to rotation. Two of the most important characteristics of angular radial transform, which distinguishes it from the moments, are that it is computationally very fast, and the high order transforms do not suffer from numerical instability.

To further improve landmark detection accuracy angular radial transform was used both for global matching of cephalograms and local template matching. Through this method, an improvement of 3% was achieved in the precision of detected landmarks. Recently, three new orthogonal rotation invariant transform, polar complex exponential transform, polar cosine transform, polar sine transform has been proposed and are collectively known as polar harmonic transforms. Through exhaustive experimentation, it is concluded that polar complex exponential transform performs better than Zernike moment and angular radial transform for global shape matching in cephalometric images. However, the computational complexity of traditional polar complex exponential transform is higher than angular radial transform. We propose a fast polar complex exponential transform method that gives lower time complexity than angular radial transform. Hence polar complex exponential transform may be used to further improve the detection accuracy of landmarks.