CHAPTER 8

CONCLUSIONS AND FUTURE WORK

A summary of the main contributions of the thesis is presented and the concluding remarks of the research that was undertaken are discussed. The conclusions are followed by suggestions regarding future research.

8.1 CONCLUSIONS

Despite the advances made in BAA, simplicity in design of the classifier and success rate in estimating the accurate bone age still remain as the main challenges for the technique. A large number of studies are carried out to identify best methods for bone age estimation. This research work focused on developing simple as well as accurate methods for BAA. Four such BAA methods have been developed for accurate bone age estimation by deploying simpler yet robust methods for feature extraction and classification. The approaches made use of diverse classification methods on different combinations of wrist bones. Medical studies reveal that a BAA system that utilizes the phalanges, carpal bones, radius and ulna bones forms an efficient method for computerizing BAA throughout the entire age range (0-19 years of age). So there comes a necessity to utilize all the important wrist bones in bone age estimation. This thesis presented four methods for BAA covering the most important wrist bones, namely the carpals, the EMROI of phalanges, the radius and the ulna. Morphological feature extraction was done in order to extract geometric features from the selected ROI bones, which describe the morphology of the bone. These features were utilized to train the system in classifying the radiograph into the corresponding age class, which was in turn mapped on to the final bone age.

The proposed convex hull based approach estimated the bone age from the carpal bones by determining the convex hull for each carpal bone and extracting three features from each of them namely, Solidity, Convexity and Concavity. The final
classification was done by finding the closest match for the test feature set in the trained feature vector. The proposed feature ratio approach used features extracted from the carpals and radius bone for BAA. From the extracted features, two feature ratios were computed, \( CROI-Ratio \) and \( RROI-Ratio \), which were in turn used to find the mean feature ratios, \( MCRatio \) and \( MRRatio \). The above two ratios of the test image were subtracted from those already stored in the feature vector. The class with the minimum values for both the differences was output as the final age class.

The proposed decision tree approach made use of epiphyseal features of the radius and ulna bones, namely \( R_{Presence}, U_{Presence}, R_{Diameter}, R_{Circularity}, U_{Circularity}, R_{Roughness}, U_{Roughness}, R_{Capping}, U_{Capping}, R_{Fusion}, \) and \( U_{Fusion} \). These features were fed into the decision tree classifier, based on the gender and the output was the final bone age class to which the radiograph belongs.

The proposed Hausdorff distance approach extended the work done by Giordano et al (2010) in estimating the bone age from EMROI joints. The system constructed the feature vector \( F_{new}^{Bone \_Stage} \), from the features \( d_{meta}, dnv1, \ldots, dnv5, area1, \ldots, area6, \) and \( dh_{epi} \) along with \( MED \), the mean of three additional distance measures from the middle phalanx EMROI of the 5\(^{th} \) finger. Finally the bone stage classification was done by calculating the Hausdorff distance between the features extracted from the test image and the \( F_{new}^{Bone \_Stage} \) feature vector. All the above four approaches were compared using the \( MeanMetric \) parameter, and the results obtained are as follows. The proposed convex hull approach proved to be the best with the score 98.54\%. Next best was the proposed feature ratio approach with score 97\%. The proposed decision tree approach achieved 96.84\% and Hausdorff distance achieved 96.83\%. The adopted approaches were found reasonably appropriate for the age group of 0-10 years since the main wrist bones that contribute toward BAA at that stage were considered. The proposed bone age estimation methods proved to be efficient for the age group of 0-10 years for both male and female cases, when validated with the results obtained from two radiologists. The significance of the research is worthy in the fields of pediatric radiology and pediatric endocrinology. The former is benefited by the research in
terms of reduced human intervention, minimized intra and inter rater variability and the ease of automation. The latter is profited by more accurate results of BAA thereby improving the diagnosis and treatment of growth disorders.

8.2 FUTURE RESEARCH DIRECTIONS

Efficient methods for bone age assessment using features extracted from various wrist bones were developed. The highly contributing wrist bones namely, the carpals, the phalanges, the radius and the ulna were well utilized to assess the bone age. Few combinations of these bones were also applied for the same. But, there are still some topics not fully investigated for an integrated, computerized BAA system. First of all, a fully automatic BAA system from hand radiograph at each stage is not done yet. Also, a friendly graphical user interface system could be further developed and integrated with the proposed automatic BAA. Future research work could be focused on extending the BAA system to work on the age group above 10 years, and broadening the system to include the further hand bones such as metacarpals, and the elbow bones. Also, merging the BAA system with the Picture Archiving and Communication System (PACS) will have much clinical significance. The proposed BAA techniques when integrated with PACS will assist the radiologists in easily as well as accurately estimating the bone age from the DICOM (Digital Imaging and Communications in Medicine) images. The proposed approaches work on only a subset of the wrist bones to estimate the bone age. A complete BAA system that integrates all these important wrist bones together for BAA would prove to be a better solution. Also, BAA from hand wrist radiographs is suitable only for the age range 0 – 15 years, after which most of the wrist bones would have fused, thus providing no scope for further BAA from wrist x-rays. During the puberty stages, the radiologists make use of the elbow radiographs depicting the fusion of the radius, the ulna and the humerus bone for BAA (Dimeglio et al 2005). For age groups beyond that, the vertebral development is used by radiologists for BAA. The estimation of bone age from the elbow radiographs and the vertebral radiographs are some of the areas in which there are...
scopes for further research. There are also possibilities for BAA from other parts of
the skeleton such as the Oxford method (Acheson 1957) based on the pelvic
radiographs, the Pyle method (Pyle and Hoerr 1955) based on the knee radiographs,
and the Hoerr method (Hoerr et al 1962) based on the foot radiographs. Apart from
just assessing the bone age, these BAA systems could further be extended to include
databases containing the symptoms for endocrine disorders and their corresponding
impact on the bone age of the child. These could also include the various endocrine
disorders and the suggested alternate therapies and provisions to constantly monitor
the response in bone age for children under replacement therapies. Such fully
integrated BAA systems would be greatly beneficial clinically.