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Automated Bone Age Assessment of Older Children using the Radius

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Abstract

The Digital Hand Atlas in Assessment of Skeletal Development is a large-scale Computer Aided Diagnosis (CAD) project for automating the process of grading Skeletal Development of children from 0–18 years of age. It includes a complete collection of 1,400 normal hand X-rays of children between the ages of 0–18 years of age. Bone Age Assessment is used as an index of skeletal development for detection of growth pathologies that can be related to endocrine, malnutrition and other disease types. Previous work at the Image Processing and Informatics Lab (IPI Lab) allowed the bone age CAD algorithm to accurately assess bone age of children from 1 to 16 (male) or 14 (female) years of age using the Phalanges as well as the Carpal Bones. At the older ages (16 (male) or 14 (female) – 19 years of age) the Phalanges as well as the Carpal Bones are fully developed and do not provide well-defined features for accurate bone age assessment. Therefore integration of the Radius Bone as a region of interest (ROI) is greatly needed and will significantly improve the ability to accurately assess the bone age of older children. Preliminary studies show that an integrated Bone Age CAD that utilizes the Phalanges, Carpal Bones and Radius forms a robust method for automatic bone age assessment throughout the entire age range (1–19 years of age).

Keywords

Bone Age Assessment; CAD; Image Processing; Skeletal Imaging

1. INTRODUCTION

1.1 Current Issues in Bone Age Assessment Methods

Bone Age Assessment is used in Pediatrics to determine the stage of a subject's bone maturity during its growth from 0 to 19 years of age. Delayed or accelerated bone growth relative to a child's chronological age may be an indication of a pathological growth pattern. Examples of diseases that may cause pathological growth patterns include growth hormone deficiency, hypothyroidism, Sotos syndrome and other genetic and non-genetic pathologies. The Greulich and Pyle atlas published in 1950 form the basis of clinical bone age assessment. Radiologists use the hand radiographs of children from the G&P atlas along with descriptions of hand bone growth stages to assess a patient's bone age. Other more

recent but less commonly used methods include the Tanner and Whitehouse or TW2 Method developed in 1975. However both methods require the Radiologist to compare and manually judge stages of growth relative to an atlas. Our CAD method attempts to quantify features that correlate well with bone maturity and growth and completely automate the process of bone age assessment.

1.2 Previous Work

Previous work by Pietka, Gertych, Pospiech-Kurkowska, et al [10] used the Phalanges as the ROI for feature extraction. The dynamic changes in the Phalanges in children between the ages of 7 to 16 (male) or 14 (female) years of age provided information for bone maturity assessment within this age range. Later work by Zhang et al [4] using size and shape-based features of the Carpal Bones allowed for assessment of younger children. To allow for complete assessment of Bone Age in all children, another ROI was necessary. The Radius was chosen as the ROI of choice for older children because of its late fusion of the proximal Metaphysis and distal Epiphysis. This phenomenon is documented in the Greulich and Pyle Atlas as being later in the Radius as compared to the Phalanges. Thus allowing for assessment in the degree of fusion at the older age range using wavelet transformation based features similar to those used in the Phalanges. Due to the differing morphology between the Phalanges and the Radius, however, a new methodology is still necessary to extract the smaller sub-image of the growth plate region that will be used for feature extraction via wavelet transform. This segmentation technique is based on knowledge about the generalized morphology of the wrist. Using this knowledge along with defined landmarks, the Radius is identified and the bounding box for the sub-image is segmented from the larger wrist ROI.

2. METHODS

2.1 Localizing the Radius

This initial methodology was developed based on previous work in the phalangeal ROI in the hand. The wrist region is segmented from the overall image via a set of landmarks based on the location of the Phalanges and the hand midline. The wrist ROI is then extracted as shown in figure 1. Through textural analysis, the pixels are grouped into three sub-textures (Bone, Soft Tissue and Background) as shown in the second image in figure 1. The bone-based texture is then removed from the other two textures. A binary image shows the location of all pixels that are part of that texture group. Using knowledge of the morphology of the wrist, the Radius is selected from all other bone structure and an overall outline of the bone is formed using image processing techniques such as erosion and dilation. In addition, knowledge of the location of the Epiphysis and Metaphysis of the Radius allows missing smaller structures that may be identified as separate objects to be merged to form the image of the Radius as seen in image number 4 in figure 1. Using the width and centerline of the Radius, a box containing the growth plate is drawn automatically by the CAD algorithm. The sub-image extracted from the segmentation process illustrated by figure 1 is shown in figure 2.

2.2 Features Extraction

After the growth plate ROI is segmented (figure 2), the sub-image is then passed onto the features extraction algorithm, which calculates the energy, orientation and number of edges in the sub-image and provides 12 quantitative measurements using the wavelet transform developed for the phalanges [10]. Six of the features that show most correlated variation with bone maturity are selected and passed on to a Mamdani fuzzy inference system. For each feature, a set of membership functions are formed from training using 48 images from males of ages 14 to 18 years of age. Using statistical analysis of feature values between age groups of 14, 15, 16, 17, 18 and 19 years, groups that showed too much variation were merged.

2.3 Fuzzy Classification and Computation of Bone Age

The feature set for the images are divided into the two male and female cohorts for bone age computation, since the growth patterns and in male and female children are different [1]. For each feature, a set of 3 to 6 Gaussian membership functions were formed using the standard deviation and means from the data. Each of these membership functions represented a specific age group and depending on the feature value will contribute to each of the computed bone age output differently. A set of simple aggregation rules dictated how the membership functions were aggregated into the output membership function. The output membership functions were also Gaussian-based and depended on the standard deviation and mean of the chronological age of the 149 image training set. For our preliminary system testing we used the same image set for training and testing.

3. RESULTS

With our initial test group of Caucasian Children between the ages of 14 and 19, there were 149 images that were used for testing. The chronological age of these children does not differ more than 3 years from the projected bone age that the Pediatric Radiologist determined. The Caucasian Children also provide us with homogeneity in ethnic background in our dataset in case there are differences in growth patterns due to ethnic background. From previous experience we also found that the Caucasian dataset has the most consistent in image quality.

Our initial results show that we were able to correctly segment out the growth plate region approximately 50% of the time. Errors were a result from (1) an inability to differentiate between the carpal bones and the radius (2) mistaking the Ulna for the radius (3) unable to locate the growth plate sub-region of the carpal bone accurately. More work needs to be done to improve the accuracy of segmentation or have fail safe mechanisms when the Radius or the growth plate region cannot be segmented. In the final integrated system, images where the Radius cannot be used will rely on the phalangeal data for bone age assessment.

The results of the feature extraction are shown in figure 3 and 4, correlation coefficients are calculated from either a linear regression or exponential regression depending on the feature and were indicated by either "POLY" for linear polynomial or "EXP" for exponential. We chose to use both measures because the fuzzy inference system was able to mimic both types

of trends during training. The trends indicate that the features allow for differentiation between the lower age range of 14 to 15 and the higher age range of 17 to 19 years of age but not any higher in age range resolution.

Figures 6 to 9 shows our preliminary results of the system after the fuzzy inference engine has computed the bone age based on the radius' features. The computed CAD bone age for the new Radius results and the previous Phalangeal results are compared to the chronological age as well as the Radiologist's Readings. Tables 1 and 2 show the generalized error for the overall testing set. Relative to chronological age, the new system showed a decrease of about 0.3 years for males and 0.4 years for females.

4. DISCUSSION

The G&P atlas acknowledges natural growth variation in males from 14 to 17 years of age to have a standard deviation of 10.72 to 13.05 months. [1] Therefore, any variation of our result to within the order of 1 year can be attributed to natural variation in the population. In addition, our current system based on the Phalanges tapers off at 16 years of age for females and 17 years of age for males. Therefore any ability to differentiate between the pre-16 or pre-17 years of age and the higher age group of 18 and 19 will be contributed significantly to the overall fuzzy bone age result. This is because final system integration will allow the Phalangeal features to be aggregated with the Radii features and weighed using the fuzzy inference system to yield a final CAD bone age result.

The R-squared correlation coefficients for Radius are much lower than that of the Phalanges (approx 0.8 and above) for their optimal operational age range from 5 to 14 years. The computed bone age results show the effects of the lack of correlation in the features. Relative to the gold standard of the chronological age, it shows a stepwise output, with many of the computed bone ages clustered at 15.5 years and 17.5 years. The system however still show improvements over the Phalanges in this age range but most likely reflect the fact that Phalanges have already fully developed at this age range and no longer have enough variability for bone age assessment.

5. FUTURE WORK

The current image segmentation techniques have a high failure rate (50 %), improvements can be made looking at current error cases. Common problems include mistaking the Ulna for the Radius and having an incomplete segmentation of the Radius. Adding improvements to the current image segmentation algorithm will decrease the failure rates and increase the accuracy of the segmentation. The features are highly sensitive to whether the demarcation of the epiphysis and metaphysis is captured therefore better segmentation will yield better feature values.

For CAD system to have accuracy over the entire 0–19 year age range, the radii information has to be integrated with the current system that uses the carpal and phalangeal information for Bone Age Assessment. How this will be done and to ensure maximum reliability and performance has yet to be determined. The difficulty lies in the fact that at lower age ranges the current Radii methodology will not work as a method to determine bone age, similarly

the carpal data will not work on older children, therefore, a reliable method must be developed to cover the whole age range by efficiently aggregating information from each of the different regions.

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Fig. 1.
Outline of Image Processing algorithm to extract Growth Plate ROI from the larger Wrist ROI.

Fig. 2.

Enlarge Image showing the extracted Growth Plate ROI. Note the horizontal pattern that denotes the boundary between the epiphysis and metaphysis. This boundary lessens and eventual disappears as the child grows.

Fig. 3. Mamdani Fuzzy Inference System used to aggregate the feature values and derive a Bone Age based on feature values. The system requires training with a data set of normal children.

Fig. 4.
Feature values for the male cohort.

Fig. 5.
Feature Values for the Female Cohort

Fig. 6.
CAD Age versus Pediatric Radiologist's Reading for the Male Cohort

Fig. 7.
CAD Age versus Chronological Age for the Male Cohort

Fig. 8.
CAD Age versus Chronological Age for the Female Cohort

Fig. 9.
CAD age Versus Pediatric Radiologist's Reading for the Female Cohort

Table 1

Mean Absolute Error of the system for the Male Cohort using Phalanges and Radius based on the Chronological Age and Reading of the Pediatric Radiologist as the gold standards. The absolute mean difference for the male cohort between the Pediatric Radiologist's reading and the normal child's chronological age is 0.650 years.

	Phalanges	Radius
ChrAge	1.246 yrs	0.814 yrs
Reading	1.030 yrs	0.918 yrs

Table 2

Mean Absolute Error of the system for the Female Cohort using Phalanges and Radius based on the Chronological Age and Reading of the Pediatric Radiologist as the gold standards. The absolute mean difference for the female cohort between the Pediatric Radiologist's reading and the normal child's chronological age is 0.700 years.

	Phalanges	Radius
ChrAge	1.583 yrs	1.156 yrs
Reading	1.181 yrs	0.908 yrs